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AN INSTANT-STARTING FLUORESCENT LAMP IN SERIES WITH AN INCANDESCENT LAMP

by W. ELENBAAS and T. HOLMES*).

621.327.43

To operate a fluorescent lamp it has to be connected in series with a certain impedance. Usually a choke is employed for this purpose, and not a resistance, because with the latter there would be a rather high loss of power. This objection, however, can for the greater part be met by using an incandescent lamp as stabilizing resistance, which has the advantage that this lamp also gives light. By making some changes in the construction of the fluorescent lamp for connecting it in series with an incandescent one a solution has been found which offers certain advantages and at the same time dispenses with the starter otherwise needed for ordinary fluorescent lamps.

The tubular fluorescent lamps ("TL") hitherto commonly used in series with a stabilising apparatus, or ballast, when connected to A.C. mains of 220 V have an ignition voltage which is very much higher, with cold electrodes, than the peak voltage of the mains. Even after the electrodes have been heated up to glowing temperature the voltage required for the first ignition is usually still higher than the peak of the alternating voltage available.

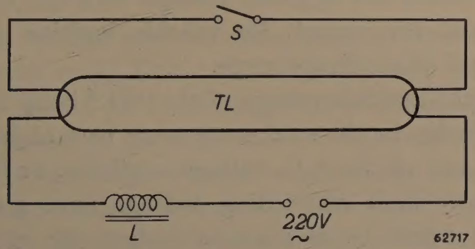

Fig. 1. Basic circuit of a "TL" lamp (*TL*) operating from A.C. mains. *L* series choke, *S* starter switch.

For the ignition of a "TL" lamp the system illustrated in *fig. 1* is often employed. When the switch *S* is closed an alternating current passes through the choke *L* and the two electrodes of the lamp, thereby heating the latter. Upon the current being interrupted by opening the switch, then, owing to the inductance of the choke, a voltage surge arises which is usually sufficient to cause the lamp to ignite. The electrodes are then kept heated by the discharge current and the re-ignition voltage remains low enough to keep the lamp burning without any further help.

The switch *S* does not necessarily have to be operated by hand but can be operated automatically. In practice automatic ignition switches (starters) are invariably used, one form of which, the glow-discharge starter, is depicted and explained in *fig. 2*. This and other forms of starters have already been fully dealt with in this journal 1)2).

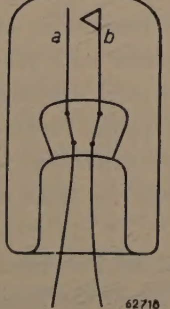

Fig. 2. Glow-discharge starter automatically performing the function of the switch *S* in fig. 1. When the mains voltage is switched on a glow discharge takes place between the electrodes *a* and *b* of the starter, thereby raising the temperature of the electrode *a*, made in the form of a bimetal, to such a level as to cause it to make contact with *b*. This stops the glow discharge, the bimetal cools down and the contact is broken. If this happens at a moment when the current is so low that the voltage surge at the choke is insufficient to cause the lamp to ignite, then the process repeats itself until the lamp does ignite. The working voltage of the "TL" lamp is not high enough to maintain a glow discharge in the starter.

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*) Philips Hamilton Works, Hamilton, Scotland.

1) A. A. Kruithof, Tubular luminescence lamps for general illumination, Philips Techn. Rev. **6**, 65-73, 1941.

2) Th. Hehenkamp, A rapid-action starter switch for fluorescent lamps, Philips Techn. Rev. **10**, 141-149, 1948/49.

The glow-discharge starter is highly dependable and has a long life, but there is the drawback that it takes two to four seconds for the lamp to ignite after switching on. This is not a serious objection for factory and office lighting where the lamps are switched on only once or twice a day, but it is inconvenient for house lighting, and that is why attempts have been made to get starters with a more rapid action. The article quoted in footnote [2]) describes a starter that has a delay, under normal conditions, of only 0.3 to 0.4 sec.

Pros and cons of an incandescent lamp compared with a stabilizing choke

The starter, however, does not provide the solution in all cases. We have in mind here the case where it is desired to replace the choke of the "TL" lamp by a series resistance. The power consumption of such a resistance is about as great as that of the "TL" lamp itself and many times greater than the losses in a choke, but this objection can for the greater part be avoided by using an incandescent lamp as resistance, this lamp then also producing a certain amount of light. An incandescent lamp is certainly a less efficient source of light than a "TL" lamp, but the reduced efficiency is offset by the following advantages:

1. An incandescent lamp (plus holder) is much cheaper than the choke hitherto used with "TL" lamps, and also lighter; the "TL" lamp fixture can then be made lighter too.

2. The power factor of an A.C. fed "TL" lamp is approximately 1 with a series resistance but only about 0.5 with a choke. (In the case of large lighting installations, in order to get a good power factor with chokes, half the number of lamps are usually provided with a ballast consisting of a choke in series with a capacitor. The inductance and the capacitance are so chosen that the current is of just the right value and leading in phase with respect to the mains voltage by about the same amount as the current of the other lamps is lagging. Naturally such a ballast with choke and capacitor is still larger, heavier and more expensive than a choke alone.)

3. An incidental advantage is that an incandescent lamp does not give rise to any hum; the hum caused by a choke can only be eliminated at the cost of special measures.

4. With the combination of a "TL" and an incandescent lamp in the same fixture a blended light is obtained which, as regards both distribution and spectral composition, is a good compromise between fluorescent light and incandescent light alone.

5. To use fluorescent lamps in places where only D.C. mains are available there is no alternative but to use a stabilizing resistance, in which case incandescent lamps will of course preferably be employed as resistances.

Let us now consider the difficulties arising when with a normal "TL" lamp the choke on the system according to fig. 1 is replaced by a suitably dimensioned incandescent lamp.

There are two difficulties to be faced. In the first place, in order to get a reasonable amount of light from the incandescent lamp in series with the "TL" lamp provision has to be made for its filament to be heated to the normal temperature (about 2700 °K) with the r.m.s. value of the voltage occurring across it when the lamp is burning. Where an incandescent lamp is connected in series with a "TL" lamp of 40 W to A.C. mains of 220 V, the r.m.s. value is about 135 V. When, however, the starter contacts are closed, almost the full mains voltage (reduced only by the voltage loss in the two filaments of the "TL" lamp) comes to lie across the incandescent lamp, which is thus heavily overloaded when switching on.

The second difficulty lies in the fact that, owing to the absence of inductance, when the contact opens, the interruption of the current does not set up a voltage surge. The action of the starter only heats the electrodes of the "TL" lamp, and, although this causes the ignition voltage to drop, it is not reduced far enough for reliable ignition without the aid of a voltage surge.

If the ignition voltage of the "TL" lamp with the electrodes in the cold state were not higher than the peak of the A.C. voltage available, or if a sufficiently high alternating voltage were available, there would be no need to preheat the electrodes and consequently no starter would be required, which is of course in itself an advantage, and then both the difficulties mentioned would be overcome.

Now there are two methods by which a sufficiently high voltage can indeed be obtained. By either of these means a higher voltage is derived from the mains voltage, on which voltage normal "TL" lamps can ignite instantaneously while the electrodes are still cold. For a lamp say 1.20 m in length and 38 mm in diameter a voltage of 400 V (r.m.s.) is required for this, whilst for longer and thinner lamps it may be as high as 750 V.

This ignition voltage is obtained by stepping up the mains voltage and when the lamp is burning a large part of it comes to lie across the ballast, which must thus be fairly large and expensive, whilst the power factor becomes unsatisfactory.

By the second method for getting a higher ignition voltage from the mains voltage a resonance circuit is employed, but owing to the rather heavy cost of the ballast very little use has been made of this method so far.

Fluorescent lamp with low ignition voltage ("TL" S lamp)

If it were possible to construct "TL" lamps igniting on a voltage below the peak voltage of 220 V mains then the starter could be dispensed with and there would be no need to have recourse to either of the means mentioned above. Now it has indeed proved to be possible to make "TL" lamps (called "TL" S lamps) of the normal dimensions with a sufficiently low ignition voltage by applying — in a manner to be described later — on the inside of the tube a conducting strip in the longitudinal direction and connecting it electrically to one of the electrodes (*fig. 3*). The resistance of this strip, as we shall presently see, must be of the order of a few thousand ohms.

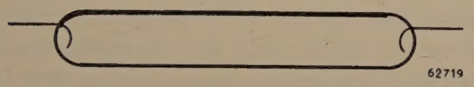

Fig. 3. Schematic cross section of the new "TL" lamp ("TL" S lamp) with conducting strip on the inside of the glass tube making contact with one of the electrodes.

This system may be understood to work in the following way. Upon the current being switched on an initial glow discharge takes place between the free end of the strip and the electrode opposite it (here the field strength is greatest). The glow-discharge current flows only during the intervals in which the electrode just mentioned is negative with respect to the strip. In the intervening intervals the discharge extends farther towards the other electrode to which the strip is connected, thereby increasing in intensity each time owing to the reduced resistance of the strip, until ultimately an arc is struck between the main electrodes.

In conformity with this explanation is the fact that in series with a choke the new starter-less lamp does not ignite so well as when it is connected in series with an incandescent lamp. Whereas the resistance of the cold incandescent lamp is negligible compared with the resistance of the strip, such is not the case with the impedance of the choke, so that when the choke is used the glow-discharge current is smaller and it is more difficult for an arc to be struck than in the case of the incandescent lamp being used.

The interval of time elapsing between the glow discharge and the normal discharge across the main electrodes depends upon the mains voltage and the resistance of the strip, as is shown by *fig. 4*. With resistances between 1500 and 2500 ohms and a mains voltage of 220 V the delay time varies very little with the resistance and is short, being of the order of 0.4-0.6 sec, and thus scarcely any longer than the delay when employing a rapid-action starter (see the article quoted in footnote [2]). With a resistance of 2000 ohms and a 10% too low mains voltage the delay is about 1 second. Even on 180 V A.C. voltage the lamp ignites within 10 seconds, which is usually regarded as the extreme limit. Consequently there is a wide margin for mains voltage fluctuations.

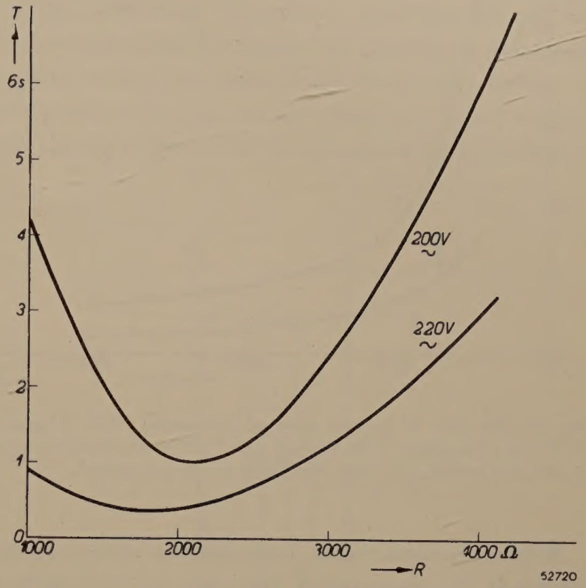

Fig. 4. The delay time T between switching on and the ignition of a "TL" S lamp of 40 W (in series with an incandescent lamp) as function of the resistance R of the strip, with 220 V and 200 V A.C. mains.

When choosing the optimum resistance one must make allowance for the loss in the strip while the lamp is burning. During the intervals in which the strip is positive with respect to the electrode opposite its free end this acts as a positive probe, with current flowing through it. In the other half-cycles it attracts positive ions towards it from the discharge, but owing to the inertness of these ions this effect is much smaller than the other. The losses in the strip appear to be roughly in inverse proportion to the resistance of the strip (see *fig. 5*, curve *1*), so that it would be desirable to have the highest possible resistance, but a limit is set to this by the delay just mentioned. For the average value of the resistance in the case of the

"TL" S lamp of 40 W 2000 ohms has been chosen, at which value the loss in the strip is still acceptable (4.5 W).

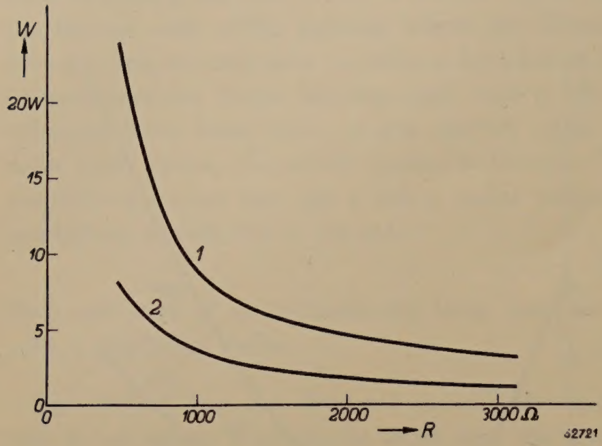

Fig. 5. The loss W in the strip of a burning "TL" S lamp of 40 W as a function of R, *1* when the strip is connected to one of the electrodes, *2* when the strip is disconnected.

When the connection between the strip and the electrode is interrupted the loss in the strip is very much less; see curve *2* in fig. 5. This is understandable, since the electron current attracted towards the strip must then at any moment be equal to the positive ion current, which, as mentioned above, is small. To take advantage of this possibility of reducing the losses one could introduce in the lamp a bimetal contact which in the cold state connects the strip to one of the electrodes (this being necessary for the ignition, as we have seen) but breaks that connection as soon as sufficient heat is developed in the burning lamp. A minor drawback to such a system is that when a lamp is switched on again just after it has been switched off it cannot reignite immediately, because it takes some time for the bimetal contact to cool down and restore the contact.

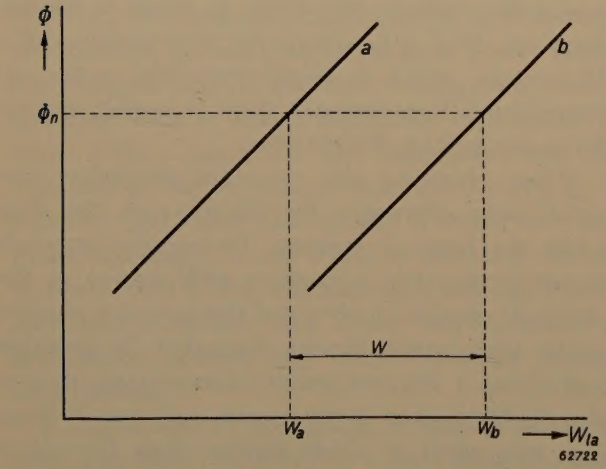

Fig. 6. Determining the loss W in the strip. The luminous flux Φ of different test lamps is measured as a function of the power consumption W_{la} in the lamp. With the exception of the strip the lamps were as nearly as possible identical. The line *a* gives $\Phi = f(W_{la})$ for a lamp without strip, *b* for a lamp with a certain strip. With $W_{la} = W_a$ and W_b respectively they yield the normal luminous flux Φ_n. $W = W_b - W_a$ is the loss in the strip.

It remains to be mentioned how the loss in the strip was measured. To this end we determined the luminous flux of test lamps with and without strip as a function of the power consumed. The strips in these lamps had different resistances and were provided with a separate lead-in so that measurements could also be taken with the strip disconnected. As a result we found almost parallel straight lines, from which the loss figures are easily derived (see *fig. 6*).

In coal-mines, where explosive gases may occur, "TL" lamps are not in themselves dangerous, but it appears that some risk attaches to the starters [3]). The "TL" S lamp, working without starter, eliminates any such possible cause of explosion.

The electrodes

The electrodes of the "TL" S lamps have to withstand heavier loading when the lamp is switched on than those of a normal "TL" lamp, since the latter lamp does not ignite until the electrodes are heated and thus ready for emission, whereas the "TL" S lamp ignites while the electrodes are still almost cold. Moreover the glow discharge between switching on and arcing causes the cathode to be bombarded with high-velocity ions.

The "TL" S lamps has therefore been fitted with special electrodes better able to withstand such conditions as these. They consist of a coiled electrode containing a larger amount of emitting material than that usually found in the electrodes of normal "TL" lamps, while the electrodes are surrounded either by a metal ring or by a closely fitting cylinder which intercepts the ions on the outside and any atomized or evaporated emitting material on the inside. Thanks to these measures the "TL" S lamp lasts on an average as long as a normal "TL" lamp.

Use on direct current

D. C. mains of 220 V are still to be found in some parts and when "TL" lamps are used on these mains they must of course be provided with a series resistance, for instance in the form of an incandescent lamp. A D.C. starter is also required, in addition to a choke (the latter only for supplying a voltage surge when the starter contact opens). But there is yet another complication. While the lamp is burning the positive ions — i.e. the mercury ions — travel, on the average, towards the cathode, and thus with the constant direction of current the mercury is gradually displaced towards the surroundings of the cathode. After the lamp has been burning about ten hours there is so little mercury vapour left in the anode half that hardly any light at all comes from that part of the lamp (it is to this mercury vapour that the ultra-violet rays, which are converted into light by the fluorescent lining, are to be attributed). The discharge in that part of the lamp is then carried by argon but this gas produces only few rays to which the fluorescent phosphors are susceptible. For this reason the mains switch is often made in such a way that every time the lamp is switched on the polarity is reversed.

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[3]) G. D. Rieck, The illumination of coal-mines and the attendant risk of explosions, Philips Techn. Rev. 10, 334-337, 1948/49.

"TL" S lamps have proved to ignite well on 220 V D.C. mains provided the strip is connected to the positive pole of the mains. There is no need for any starter and choke as required with an ordinary "TL" lamp, but the necessity of reversing the polarity now and again remains. For the lamp to ignite on either pole it must have two strips, one connected to each electrode.

Such a D.C. lamp with two strips can be used also on A.C. mains, but then the losses in the strips are twice as great as those of an A.C. lamp with one strip of the same resistance.

Manufacture of the "TL" S lamp

The strip consists of a mixture of graphite and an enamel applied on the inside of the tube in the following way. The glass tube from which the lamp is to be made and which has already been lined with the fluorescent layer is held in a horizontal position and a small wheel is passed through it. The lower part of this wheel runs through a viscous mixture of graphite, enamel and a binder, and as it rolls along inside the tube its upper part paints the strip along the wall. The composition of the mixture and the thickness of the strip applied to the tube are so chosen that after further processing the 120 cm long and 2 mm wide strip has the aforementioned resistance of about 2000 ohms. The tube then passes through a sintering process, this being necessary for the preparation of the fluorescent layer, and in that process the binder is released from the strip, while the enamel melts and the strip is baked onto the wall of the tube.

A pinch with an electrode mounted on it is then sealed in at one end of the tube. One pole of the electrode [4]) carries a chrome-iron leaf spring (with expansion coefficient equal to that of the glass) which makes contact with the strip when, in the sealing process, the glass of the tube falls inward a little, assuming the shape indicated in *fig.* 7. At the same time the enamel of the strip is softened, so that when the tube cools down the spring is firmly secured in the enamel. Instead of the chrome-iron spring a bimetallic relay can be built in which makes contact with the strip in the cold state but not in the hot state, as already mentioned, or else it can be introduced between the spring and the electrode.

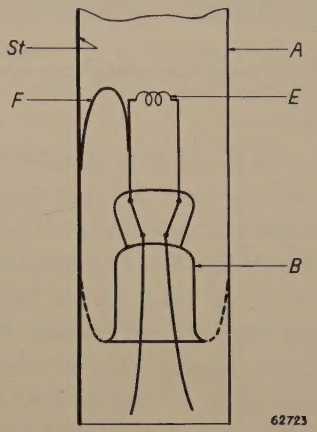

Fig. 7. *A* glass tube with fluorescent lining and conducting strip (*St*) on the inside. *B* mount with electrode *E* and chrome-iron contact spring *F*.

At the other end of the tube a mount is fused in without a contact spring (unless it is a D.C. lamp, in which case it must have two strips). The lamp is then further finished off in the normal way.

Safety caps and holders

Since, contrary to the case with an ordinary "TL" lamp, current can pass through the "TL" S lamp on 220 V without the intermediary of a starter, special measures have to be taken to avoid accidents when mounting the lamp in its holders. If one end of the lamp were to be placed in the holder while the mains switch is in the "on" position and the contact at the other end of the lamp should be touched with the hand, while the fitter himself is more or less earthed, the current (the glow-discharge current of the strip) passing through the man's

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[4]) Although for the normal working of a "TL" S lamp — in contrast to an ordinary "TL" lamp — only one connection per electrode is needed, both sides of the electrodes are supplied with lead-in wires so as to be able to heat the electrodes in the further manufacturing process for degassing and further processing the emitter.

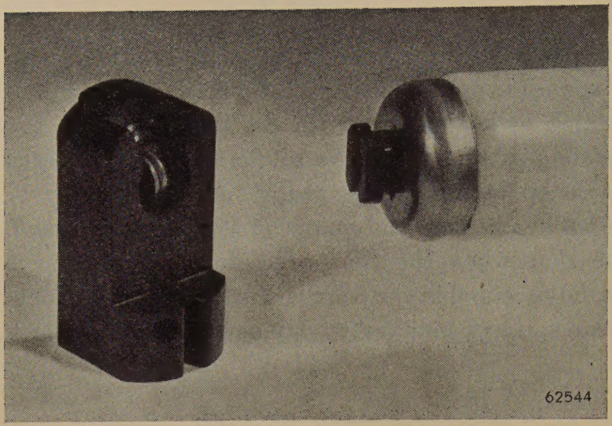

Fig. 8. Right: "TL" S lamp with safety lamp cap. *Left*: the corresponding lamp holder.

body might be dangerous. It is true that such a situation will seldom arise, because for the lamp to be inserted properly — assuming it has the normal "TL" caps — both caps have to be placed in their holders and the lamp then turned about its axis before the lamp contacts can become alive. Nevertheless with these normal caps it is still possible to turn the lamp while one cap is in the holder and to touch the live contact pins at the other end.

Means have therefore been sought to avoid the possibility of such accidents occurring. *Fig. 8* shows a new construction of lamp cap and holder. The insulating cap has a slot in which the contact (the "TL" S lamp needs only one contact at each end) is sunk so deep that it cannot be reached with what is known as a standard finger (a metal rod of standardized dimensions, in the form of a finger, used to see whether any live point can be touched with a finger). Furthermore the holder is so constructed that the circuit cannot be closed before the lamp has been turned; thus without a lamp in the holders the lamp-holder contacts cannot become alive.

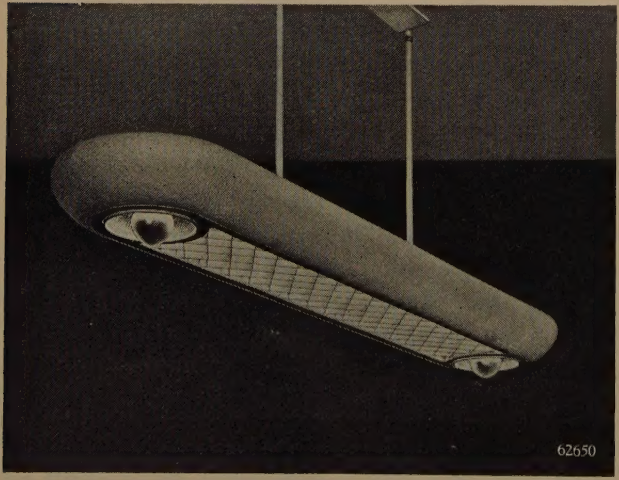

Fig. 9. Fixture (type XA 240) of "Plastocel" with two "TL" S lamps of 40 W and two incandescent lamps.

Thanks to these precautions the "TL" S lamp can therefore be placed in its holders with perfect safety.

The fixture

Fig. 9 shows a fixture carrying two "TL" S lamps of 40 W and the two auxiliary incandescent lamps 5). On 220 V A.C. mains these four lamps together yield a luminous flux of 5600 lumens for a consumption of 215 W. The photograph in *fig. 10* shows how these fixtures are used in practice.

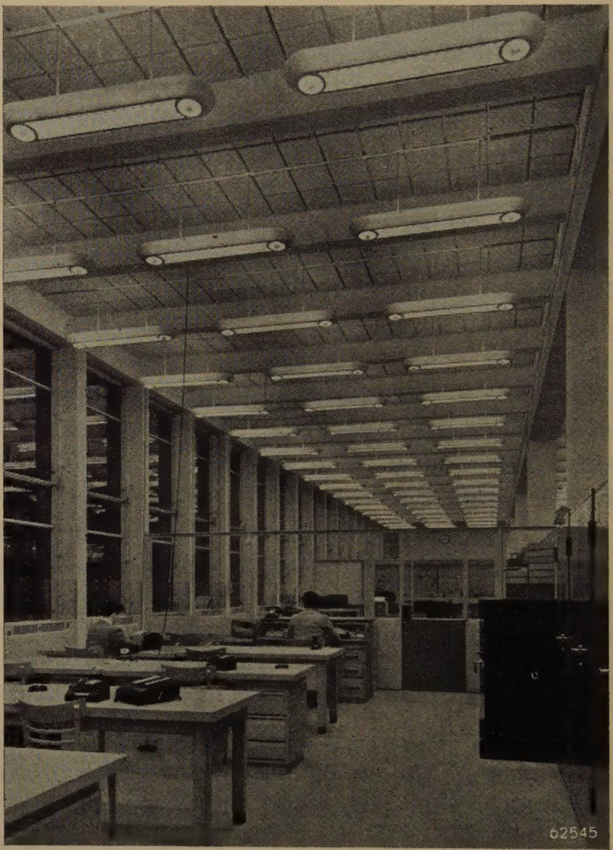

Fig. 10. Room in Philips' head offices at Eindhoven illuminated with lamps in fixtures of the type XA 240 (fig. 9).

The fixture consists of "Plastocel" (a highly diffusing and washable fibrous material) and a metal frame, which, owing to the absence of any heavy parts like chokes, can be kept very light in weight. The luminous flux from the two incandescent lamps is directed downward by reflectors, so that the illumination obtained on a working plane underneath the fixture is greater than that obtained from an ordinary "TL" fixture supplying the same

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5) For A.C. mains of 220 V an incandescent lamp for 135 V, 0.5 A, is needed, and for 220 V D.C. mains one of 110 V, 0.36 A. Since these incandescent lamps are exposed to relatively greater voltage fluctations than when connected to the mains direct, lamps of a special type must be used.

total luminous flux. The "TL" S lamps provide mainly the diffuse light. *Fig. 11* gives the distribution of the illumination on a working plane 2.5 m below the fixture. This distribution has proved to be very satisfactory, for instance, for shop lighting.

Finally it is to be noted that owing to the single-pole end contacts of these "TL" S lamps and the absence of starters the wiring in the fixture is extremely simple.

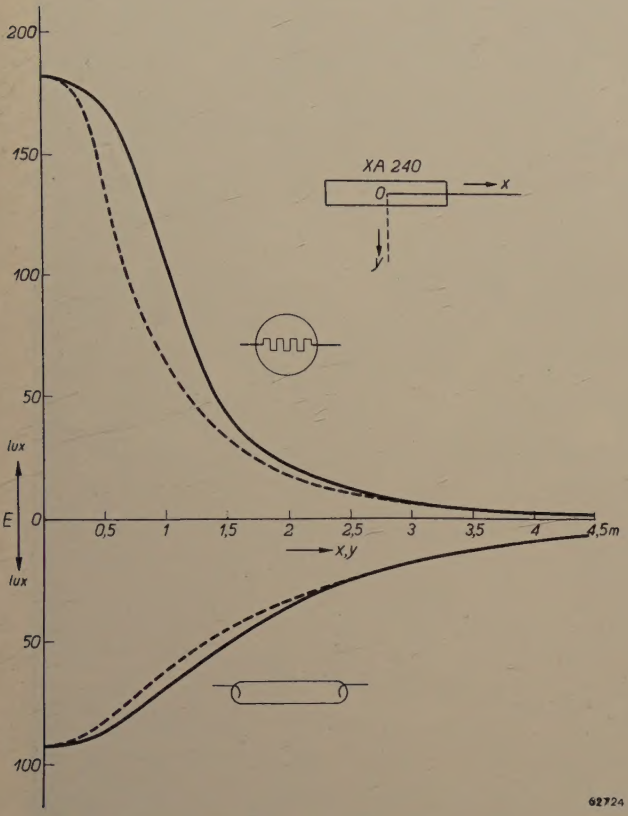


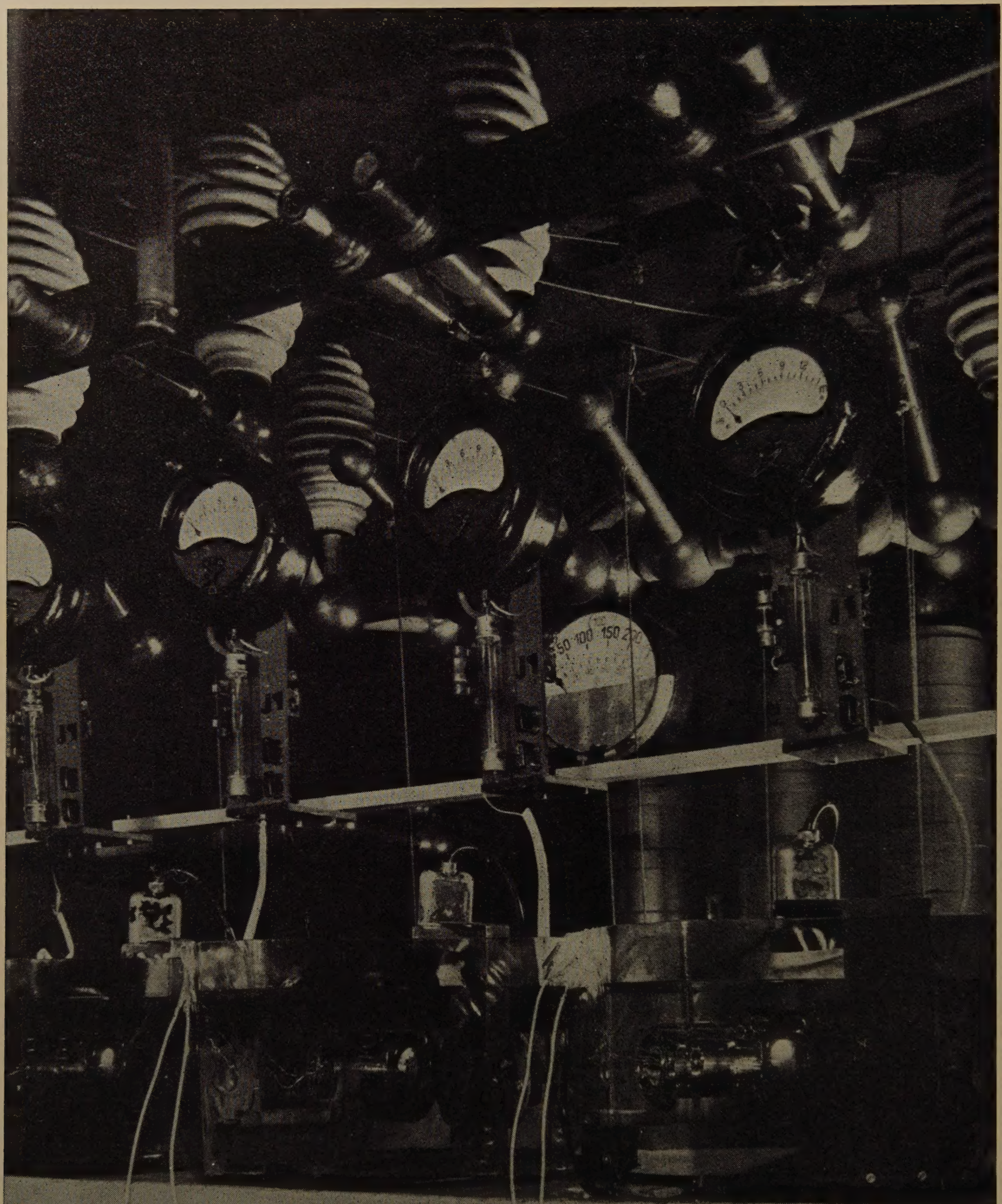
Fig. 11. Illumination E (with a luminous flux of 5600 lm) on a working plane 2.5 m below an XA 240 fixture, as a function of the distance x, y from the centre parallel to the longitudinal direction (full line) and at right angles thereto (dotted line). The contribution from the incandescent lamps has been plotted upwards, that from the "TL" S lamps downwards; the distance between the curves is thus a measure for the total illumination. Immediately underneath the fixture there is 280 lux, i.e. 185 lux from the incandescent lamps and 95 lux from the "TL" S lamps. Already at a fairly short distance from the centre the contribution from the "TL" S lamps is greater than that from the incandescent lamps.

Flickering

The asymmetry in the A.C. design of the "TL" S lamp — due to one of the electrodes being connected to a conducting strip — results in the average luminous flux in one half-cycle differing somewhat from that in the other half-cycle. Consequently the fundamental frequency of the flickering common to all lamps operating on A.C. is not twice the mains frequency but the mains frequency itself. Although this fluctuation of the light with the mains frequency is only small in amplitude the effect is still noticeable because the eye is more sensitive to flickering at a frequency of 50 c/s than to flickering of 100 c/s. When, however, two "TL" S lamps are used in one fixture, as in fig. 9, they can be so inserted that the strips are connected to different poles of the mains (it can be seen from the lamps at which end the strip is connected), the two flickerings with the mains frequency then compensating each other, so that the result is the normal imperceptible flickering with twice the mains frequency.

Summary. In some cases it is advantageous to replace the ballast of tubular fluorescent lamps ("TL" lamps) for 220 V A.C. by a special incandescent lamp, because, for one reason, the latter is cheaper and lighter in weight. If this is done with ordinary "TL" lamps, using the customary circuit with starter, there is the difficulty of the incandescent lamp being strongly overloaded each time the current is switched on, whilst moreover the ignition is unreliable. These difficulties have been overcome by the construction of a new lamp (the "TL" S lamp) provided with a strip, connected to one of the electrodes, along the inside of the glass tube (resistance of the strip about 2000 ohms). The ignition voltage of this lamp, with cold electrodes, is so low that it can be relied upon to ignite even at 180 V A.C. without any voltage surge. No starter is therefore needed. On 220 V the lamp ignites within 0.4 - 0.6 sec after switching on. For D.C. mains of 220 V a special construction of this lamp is required, with two strips each connected to an electrode. — The lamp caps and holders are so constructed that no live parts can be touched when inserting the lamp. A fixture of "Plastocel" is described for two "TL" S lamps of 40 W and two incandescent lamps, the four lamps together yielding 5600 lumens for a consumption of 215 W.

TESTING "ROTALIX" X-RAY TUBES



In this installation four X-ray tubes are tested at a time, being subjected to loads of different voltages, currents and times. The tubes, three of which are seen in the photograph, are placed in the oil-filled glass containers seen at the bottom (imitating actual working conditions). Tube currents are measured by the four meters, underneath each of which is a tubular glow-lamp serving as an indicator for any electrical disturbance in the X-ray tube. The high tension, the filament voltage and the filament current are measured by separate meters (not visible here).

THE COLOUR TRIANGLE

by W. de GROOT and A. A. KRUITHOF.

535.617

The coloured plate appended to this article is a reproduction of a picture in oils representing the chromaticity diagram in ICI coordinates. By way of explanation a brief account is given of the formation of the colour space and of the colour plane.

Conception of luminance (objective brightness) and colour

A luminous surface emitting per unit of area, per unit of solid angle and per unit of time an energy $E(\lambda)\Delta\lambda$ in the wavelength range $\lambda \rightarrow \lambda + \Delta\lambda$ in the direction of the eye has an (objective) brightness or luminance:

$$L = K \int E(\lambda) V(\lambda)\, \mathrm{d}\lambda\, . \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

The integration has to be extended over the whole of the spectrum of the electromagnetic radiation ($0 < \lambda < \infty$). K is the photometric radiation equivalent (about 650 lm/W) and $V(\lambda)$ the visibility function. The function $V(\lambda)$, which assumes values differing from zero only in the interval 400 mμ $< \lambda <$ 780 mμ, is an average derived from photometric tests with a large number of observers and standardized by the International Commission on Illumination (I.C.I.) in 1924.

Two luminous surfaces with spectral distributions $E_1(\lambda)$ and $E_2(\lambda)$ are said to have equal luminance when

$$\int E_1(\lambda)\, V(\lambda)\, \mathrm{d}\lambda = \int E_2(\lambda)\, V(\lambda)\, \mathrm{d}\lambda. \quad . \qquad (2)$$

For an observer whose individual visibility function $V_{\mathrm{ind}}(\lambda)$ corresponds to $V(\lambda)$ these surfaces will in fact appear to be of equal brightness.

Formula (1), from which L can be calculated if $E(\lambda)$ is known, also enables us to compare the luminances of lighted surfaces objectively. All that is needed is a photocell fitted with such a filter that the sensitivity for radiations of different wavelengths depends in the same way upon λ as $V(\lambda)$; the current flowing through the photocell when it is exposed to the radiation from the luminous surface is then a measure for the quantity $\int E(\lambda)\, V(\lambda)\, \mathrm{d}\lambda$ and thus also for the luminance L.

Apart from calculation and the described measurement with the aid of a photocell, luminances can also be compared subjectively according to known photometric methods, at least provided an observer is available whose individual visibility function corresponds closely to the standardized visibility function $V(\lambda)$. One then makes use, in fact, of formula (2), where for instance E_1 is proportional to the spectral energy of the luminous surface to be measured and E_2 refers to a perfectly diffusing surface, illuminated with the standard source of light, which is compared with the first surface.

There is a certain anology between the mathematical description of the conception of "luminance" (eq. (1)) and that of the conception of "colour". It has in fact been proved that the colour of a luminous surface can be fully characterized by three numbers denoted by the letters X, Y and Z, whereby

$$\left.\begin{aligned} X &= \int E(\lambda)\, \overline{X}(\lambda)\, \mathrm{d}\lambda, \\ Y &= \int E(\lambda)\, \overline{Y}(\lambda)\, \mathrm{d}\lambda, \\ Z &= \int E(\lambda)\, \overline{Z}(\lambda)\, \mathrm{d}\lambda. \end{aligned}\right\} \quad . \quad . \quad . \quad . \qquad (3)$$

These integrals bear the same character as the integral (1), $\overline{Y}(\lambda)$ even being identical with $V(\lambda)$, so that, with a factor, Y represents at the same time the luminance L. The functions $\overline{X}(\lambda)$, $\overline{Y}(\lambda)$ and $\overline{Z}(\lambda)$ (called the distribution curves or tristimulus values for the "spectrum of constant energy") were standardized in 1931 by the I.C.I. as a result of extensive tests with a number of observers. For every wavelength they have a positive value and are graphically represented in *fig. 1* 1)).

Two luminous surfaces *1* and *2* are said to have the same colour (i.e. are indistinguishable) when

$$X_1 = X_2, \quad Y_1 = Y_2 \ \text{and} \ Z_1 = Z_2\, .$$

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1) In accordance with P. J. Bouma, for these functions we have introduced the notations $\overline{X}$, $\overline{Y}$, $\overline{Z}$ (capitals) because they appear to be more logical than the ususl notation $\bar{x}$, $\bar{y}$, $\bar{z}$ (in small letters).

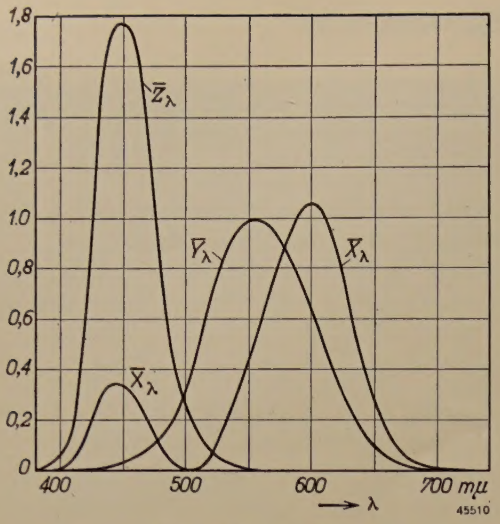

Fig. 1. The functions $\overline{X}(\lambda)$, $\overline{Y}(\lambda)$ and $\overline{Z}(\lambda)$, the so-called spectral distribution curves or tristimulus values (for the spectrum of constant energy).

We assume the theory of Young and Helmholtz to be correct, according to which colours are perceived by means of three kinds of receptors present in the retina, having hypothetical spectral sensitivities $R(\lambda)$, $G(\lambda)$ and $B(\lambda)$. Then the functions $\overline{X}(\lambda)$, $\overline{Y}(\lambda)$ and $\overline{Z}(\lambda)$ must be linear combinations of $R(\lambda)$, $G(\lambda)$ and $B(\lambda)$. There is still, however, some uncertainty about the coefficients in these linear relations and thus about the functions $R(\lambda)$, $G(\lambda)$ and $B(\lambda)$.

The mutual deviations of the functions corresponding to $\overline{X}(\lambda)$, $\overline{Y}(\lambda)$ and $\overline{Z}(\lambda)$ of different observers are relatively small, at least if certain groups of persons — called protanopes and deuteranopes — showing decidedly systematic aberrations are excluded; such people are not suitable for carrying out subjective colorimetric measurements which should hold for normal persons.

The fact that the individual visibility function $V_{\text{ind}}(\lambda)$ of different, colorimetrically normal, observers differs from the standardized average function $V(\lambda)$ much more than the individual function corresponding to $\overline{Y}(\lambda)$, does not detract from the truth of the statement that $V(\lambda)$ and $\overline{Y}(\lambda)$ are identical, since $V_{\text{ind}}(\lambda)$ may be regarded as being built up from the functions $R(\lambda)$, $G(\lambda)$ and $B(\lambda)$ and thus also from the functions $\overline{X}(\lambda)$, $\overline{Y}(\lambda)$ and $\overline{Z}(\lambda)$. Thus

$$V_{\text{ind}}(\lambda) = a\overline{X}(\lambda) + b\overline{Y}(\lambda) + c\overline{Z}(\lambda),$$

in which the standardized functions may be taken for $\overline{X}(\lambda)$, $\overline{Y}(\lambda)$ and $\overline{Z}(\lambda)$ and the coefficients a, b and c differ as between one person and another [2]). On the average $a = c = 0$ and $b = 1$.

The numbers X, Y and Z characterizing a colour can be determined, just like L, in different ways.

In the first place, when $E(\lambda)$ has been measured, X, Y and Z can be calculated from (3).

In the second place X, Y and Z can also be determined by objective measuring, namely by using three photocells each with such a filter that the sensitivities of the combinations are proportional to $\overline{X}(\lambda)$, $\overline{Y}(\lambda)$ and $\overline{Z}(\lambda)$ respectively. Such objective colorimetric measuring methods are in fact employed.

Finally, X, Y and Z can also be determined subjectively, by making in a suitable instrument (colorimeter) the colour of the surface concerned indistinguishable from that of another, white, reference surface illuminated with an additive mixture of three coloured standard sources of light each of which gives that surface respectively the luminance L_1, L_2 and L_3. X, Y and Z can then easily be calculated from the three luminances L_1, L_2 and L_3, or found, with the aid of the tables or graphs supplied with the instrument, from the settings a_1, a_2 and a_3 of the control knobs with which L_1, L_2 and L_3 were brought to the right values.

The colour space

When the values of X, Y and Z have been determined for a large number of colours one can imagine these as being plotted as coordinates in a tri-axial system of coordinates. The colours are then said to be represented in a colour space. In this colour space a special part is played by colours of which the representative points lie on an arbitrary line drawn through the origin. Such a series of colours is seen when a white source of light is brought closer and closer to a coloured surface (or inversely a coloured light is brought closer to a "white" surface). The closer the light source is brought to the surface the greater is the amount of radiation $E(\lambda)$ reflected from that surface, the ratios $X:Y:Z$ remaining unchanged. In plain words one would say that as the lamp is brought closer the "colour" does not change but becomes brighter. We prefer, however, to say that two colours differing only in brightness are "different". For what does not change in the test described we introduce the name colour species or chromaticity. We can then describe the said test with the words: The colours perceived when a lamp is brought closer to a surface differ in brightness but belong to the same colour species (have the same chromaticity).

The colour plane

Since a colour is fully determined by three quantities, it is obvious that two quantities are sufficient for determining a chromaticity. For this purpose two of the three quantities x, y and z are taken, which are given by:

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[2]) H. de Vries, Physica, The Hague **14**, 319-366, 367-380, 1948.

$$\left.\begin{aligned} x &= \frac{X}{X+Y+Z}, \\ y &= \frac{Y}{X+Y+Z}, \\ z &= \frac{Z}{X+Y+Z}, \end{aligned}\right\} \quad . \; . \; . \; . \quad (4)$$

and hence

$$x+y+z=1.$$

From the fact that two quantities are sufficient it follows that chromaticities can be represented in a plane. If, for instance, x and y are plotted as coordinates in a rectangular system of axes then all colour points [3]) are contained within the triangle determined by the x-axis ($y = 0$), the y-axis ($x = 0$) and the straight line $x + y = 1$; in fact, since $\overline{X}(\lambda)$, $\overline{Y}(\lambda)$ and $\overline{Z}(\lambda)$ are positive for any value of λ, and thus also the quantities X, Y and Z are positive, none of the three quantities x, y and z can be negative.

All kinds of chromaticities can now be localized in the plane. Inter alia, the colour point can be indicated for any monochromatic radiation with wavelength λ, since in this case $X : Y : Z = \overline{X}(\lambda) : \overline{Y}(\lambda) : \overline{Z}(\lambda)$, from which the corresponding x and y can be calculated for any wavelength. A curve drawn through the points thus obtained is called the spectrum locus. This curve lies indeed entirely within the aforementioned triangle and touches its sides at two places. It has the shape of a horseshoe (see fig. 2).

The mixture law

A peculiar property of the colour plane, as a direct consequence of the properties of the eye determined in formula (3), is the following. When a white surface is illuminated with two coloured lights simultaneously and thus, so to say, the colours which would result from the illumination with only one light source at a time are additively mixed, then the resulting point in the chromaticity diagram lies on the line connecting the colour points of the components. The position of the point representing the mixture on that line can be deduced from the well-known centre of gravity rule by allotting to each of the component chromaticities a "weight" equal to the quantity $(X + Y + Z)$ or Y/y (cf. formula (4)).

From this it follows that the colour points of all realizable chromaticities lie within the figure bounded by the spectrum locus and the straight line connecting the extremities of that curve. On this straight line, called the purple line, lie the colour points of the chromaticities obtained when the extreme spectral red is additively mixed with the extreme spectral violet.

Two colours which, if mixed in suitable proportions, give the chromaticity white (for which by definition $x = {}^1/_3, y = {}^1/_3$) are said to be complementary. In particular, any colour having its colour point on the purple line is complementary to a spectral colour (494 mμ $<\lambda<$ 570 mμ).

A given colour can always be regarded as being a mixture of the aforementioned white with a spectral colour or with a colour lying on the purple line. The quotient of the required brightness of the spectral colour (or of the colour on the purple line) and the total brightness of the given colour is known as the colorometric purity p. The wavelength of the spectral colour that has to be additively mixed with white to imitate a given colour species is called the dominant wavelength. For the purple colours the wavelength of the complementary spectral colour is chosen for this purpose, this case being distinguished by a minus sign.

Realization of the colour plane

Once it is known that a point x, y in the colour plane represents a certain chromaticity one would like to know what that chromaticity looks like.

To give an idea of the distribution of the chromaticities over the colour plane, coloured strips of paper (e.g. colour samples from the Munsell atlas) could be pasted over their corresponding positions in the chromaticity diagram.

One could also determine the colour points of a number of oil paints and give a dab of these paints on the right places in the diagram. When this has been done, one could try to make the intermediate chromaticities with suitable paints and thus complete the whole of the chromaticity diagram. The attached coloured plate is a reproduction of the result of such an attempt [4]).

Of course this result is not without its defects, but when viewed from a distance the plate gives a reasonable impression of the manner in which the chromaticities are distributed over the diagram.

In one respect the plate is certainly incorrect.

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[3]) For the sake of brevity the expression colour point is used also for the colour plane, although strictly we should still speak of colour-species point or chromaticity point.

[4]) We are greatly indebted to A. R. W. Muijen of this laboratory for the manner in which he has performed this task.

The fact is that if it is desired to represent highly saturated colours, paints must be used which show a reflectivity differing from zero only in a very limited spectral range and thus look very dark in comparison with less saturated colours. With the customary paints, and starting from white, one therefore does not get much farther than about halfway to the limit of the spectral curve. Only in yellow and violet is it possible to get with oil paints a rendering of chromaticities close to the edge of the range. For the sake of the total impression the plate has, however, been filled in everywhere right up to the edge, be it with colours lacking in saturation.

It is well to point out that in order to get the right impression of the chromaticity diagram the reproduction should be viewed in daylight because the calculation of the colour points of the applied paints has been carried out for daylight.

For further orientation in the diagram a line drawing of the colour triangle is given in *fig. 2* in which the values of x and y are indicated, as also the wavelengths of the spectral colours and, on the purple line, the wavelengths of the spectral colours complementary to purple colours. In addition, the lines of constant dominant wavelength and the lines of constant colorimetric purity are shown.

The number of chromaticities

When trying to arrive at a colorimetric match between two colours *1* and *2*, where, for instance, *1* is a given colour and *2* a variable additive mixture of three "primary colours", one will aim at obtaining the equalities:

$$X_1 = X_2,\ \ Y_1 = Y_2,\ \ Z_1 = Z_2\,.$$

In practice, however, the two halves of the field of vision in the colorimeter will be indistinguishable already, while there is in fact still a difference

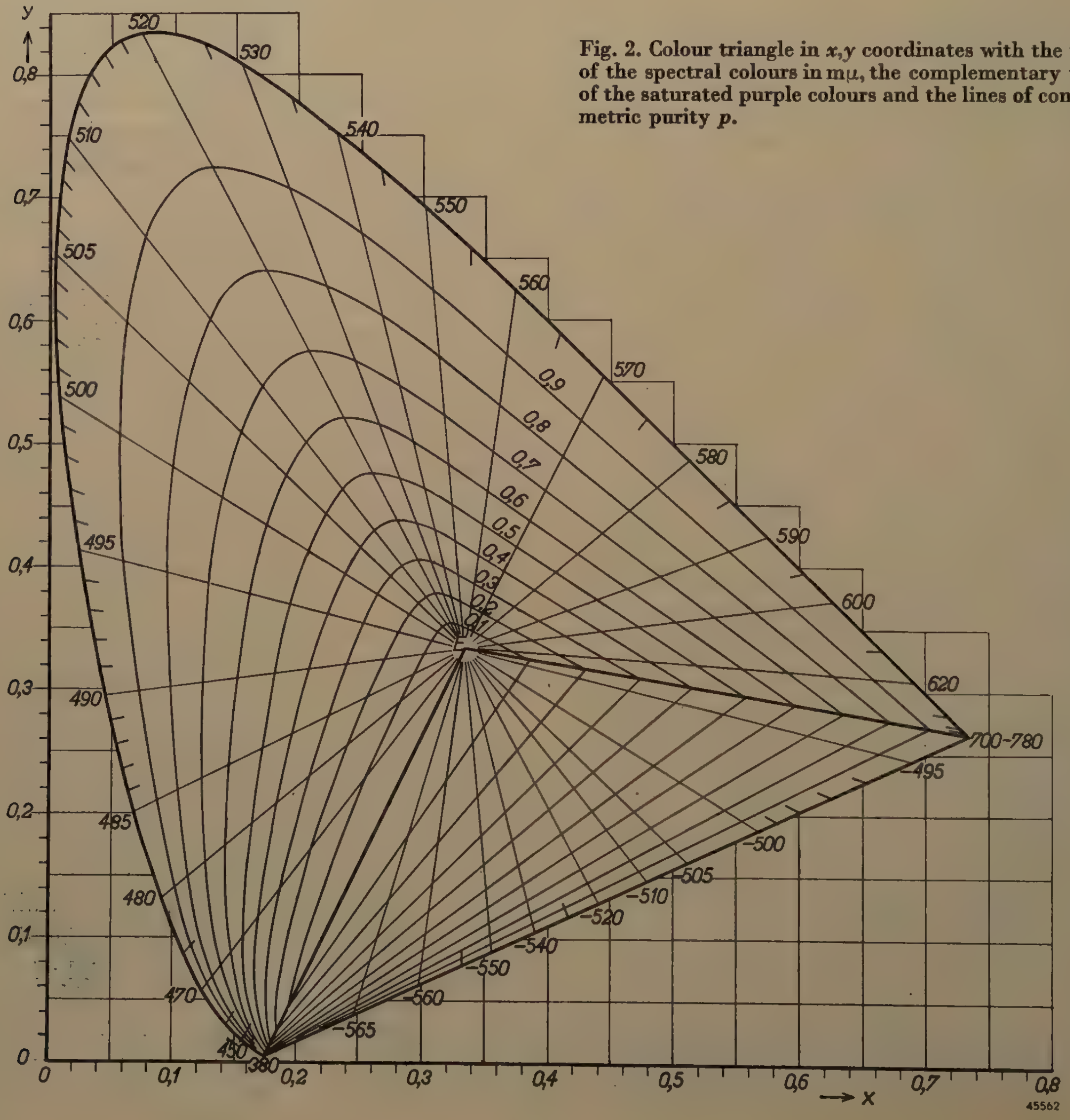

Fig. 2. Colour triangle in x,y coordinates with the wavelengths of the spectral colours in mμ, the complementary wavelengths of the saturated purple colours and the lines of constant colorimetric purity p.

(expressed by ΔX, ΔY and ΔZ) between them. Starting from a certain point x, y in the chromaticity diagram, for a given luminance and for a certain direction through that point, it can be deduced from a large number of such observations what average departure from the given chromaticity is possible along that line without disturbing the match of the two colours to a perceptible degree. Thus along each line through x, y two points are found, at either side of the point x, y. Repeating this construction for a number of directions through the same point x, y and connecting the points thereby found, a curve is obtained around the starting point. Such a curve is found to have practically the shape of an ellipse. The size and orientation of this ellipse differ for different points of the chromaticity diagram. A number of such ellipses have been determined by Mc Adam[5]. The area of the ellipse, multiplied by a suitable numerical factor, can be taken as a measure of the space occupied by a chromaticity in the chromaticity diagram. From this it is possible to calculate the number of different chromaticities, of which there appear to be over 10,000.

Colour stimulus and colour sensation

We have seen that a colour is fully determined by three data, e.g. by the coordinates X, Y and Z in the colour space or by luminance and chromaticity (determined by x and y), or by the luminance, the dominant wavelength and the colometric purity.

The question whether a colour determined in this way has the same appearance under all circumstances has to be answered in the negative. A piece of red paper, for instance, reflecting 25% of the incident light will appear to be browner against a white background than against a black one. A piece of grey paper, for which $x = {}^1/_3$, $y = {}^1/_3$, appears to be bluish against a yellow background and yellowish against a blue background, greenish against a red and reddish against a green background.

This difference between the conceptions of colour stimulus and colour sensation has been discussed elsewhere in this journal. In respect to this and other more detailed questions on the subject reference is made to the literature quoted at the end of this article.

Producing a colour plane by means of coloured lights

The colour plane, or at least part of it, can be produced in another way by making use of the so-called first law of Grassmann, according to which any chromaticity can be perfectly imitatedb ya na dditive mixture of three arbitrarily chosen chromaticities, say a red (r), a green (g) and a blue (b), with spectral distributions $E_r(\lambda)$, $E_g(\lambda)$ and $E_b(\lambda)$, respectively. From equation (3) it follows that for this purpose three constants, K_1, K_2, K_3, have to be determined, such that

$$\left.\begin{aligned} \int E\bar{X}\mathrm{d}\lambda &= K_1\int E_r\bar{X}\mathrm{d}\lambda + K_2\int E_g\bar{X}\mathrm{d}\lambda + K_3\int E_b\bar{X}\mathrm{d}\lambda \\ \int E\bar{Y}\mathrm{d}\lambda &= K_1\int E_r\bar{Y}\mathrm{d}\lambda + K_2\int E_g\bar{Y}\mathrm{d}\lambda + K_3\int E_b\bar{Y}\mathrm{d}\lambda \\ \int E\bar{Z}\,\mathrm{d}\lambda &= K_1\int E_r\bar{Z}\,\mathrm{d}\lambda + K_2\int E_g\bar{Z}\,\mathrm{d}\lambda + K_3\int E_b\bar{Z}\,\mathrm{d}\lambda \end{aligned}\right\} \quad (5)$$

These equations can always be solved provided the coefficient determinant $\Delta \neq 0$, a condition which is complied with in the case of the colours red, green and blue. K_1, K_2 and K_3 are positive if the colour point of the colour to be imitated lies inside the triangle rgb; K_1, K_2 and K_3 may be regarded as colour coordinates. The corresponding colour space is to be regarded as an *affine* transformation of the XYZ space. In a manner similar to that described above, from this three-dimensional space it is possible to derive a two-dimensional representation of all chromaticities which in the xy-plane fall inside the triangle rgb, this being done by introducing the quantities

$$\left.\begin{aligned} k_1 &= \frac{K_1}{K_1+K_2+K_3}, \\ k_2 &= \frac{K_2}{K_1+K_2+K_3}, \\ k_3 &= \frac{K_3}{K_1+K_2+K_3}. \end{aligned}\right\} \quad \ldots\ldots \quad (6)$$

As previously done for x and y, k_1 and k_2 for instance can be regarded as cartesian coordinates, or k_1, k_2 and k_3 can be plotted as triangular coordinates in an equilateral triangle (*fig. 3*). The relation between

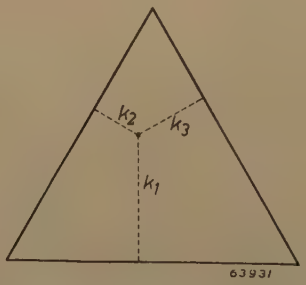

Fig. 3. Triangular coordinates k_1, k_2, k_3.

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[5] If $A(x, y)$ is the area of the ellipse described above around the point x, y then the number of chromaticities is

$$\int \frac{\mathrm{d}x\,\mathrm{d}y}{k\,A(x,y)},$$

in which k is a numerical [factor. The integral has to be extended over the area of realizable chromaticities.
D. L. Mc Adam, Visual sensitivities to color differences, J. Opt. Soc. Amer. **32**, 247-274, 1942 and D. L. Mc Adam, Documenta Ophtalmologica **3**, 214-239, 1949.

this $k_1k_2k_3$-plane and the xy-plane is given by a *projective* transformation.

In *fig. 4* a device is illustrated whereby the colours in the $k_1k_2k_3$-plane automatically occur in the right places. S_1 is a metal screen with an aperture in the shape of an equilateral triangle and covered at the back with a plate of frosted glass. S_2 is a metal plate of the same shape as the aperture in S_1 but placed upside down. The screen S_3 has three rectangular apertures so arranged that their long sides make angles of 120° with each other. The centres M_1, M_2, M_3 of the short sides facing outward form an equilateral triangle of the same size and in the same position as the aperture in S_1. The distance S_1S_2 is twice the distance S_2S_3. The centres of all triangles lie on one line normal to the three screens. Otherwise the dimensions are arbitrary. In an actual model, for instance, the height of the triangles was 10 cm and S_1S_2 was about 25 cm. The openings r, g, b in S_3 have been covered respectively with a red, a green and a blue filter (Wratten filters 29 F, 61,47). Behind the screen S_3 is a plate of frosted glass, illuminated uniformly with a strong incandescent lamp.

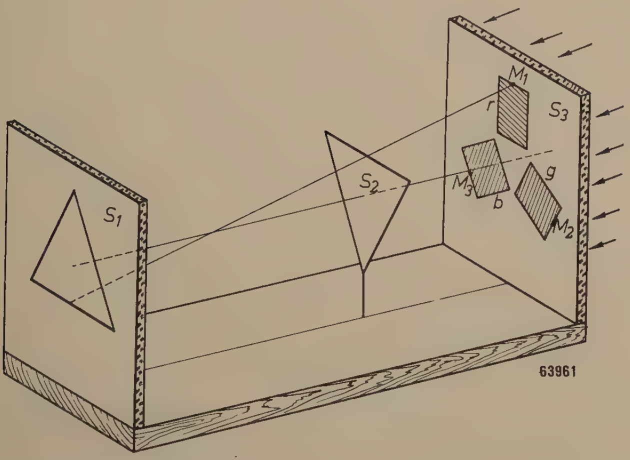

Fig. 4. Set-up for displaying the colour plane in triangular coordinates.

Let us now ascertain what the colour is at a point P lying inside the diaphragm in the plane of S_1, having the triangular coordinates k_1, k_2, k_3 (taking the height of the triangle as equal to 1). Imagining the screen S_2 as being projected from P onto S_3, then we get on S_3 a triangular "shadow" of S_2 (*fig. 5*). Only those parts of the rectangular apertures falling outside this shadow can transmit light to P. The heights of these rectangular pieces are respectively $k_1/2$, $k_2/2$ and $k_3/2$. If the other sides are denoted by $2b_1$, $2b_2$ and $2b_3$ then these areas are equal to k_1b_1, k_2b_2 and k_3b_3. Now if $E_0(\lambda)$ is the spectral distribution of the lamp illuminating S_3 and $r(\lambda)$, $g(\lambda)$, $b(\lambda)$ represent the spectral transmission factors of the three filters, then — disregarding the effect of the obliquity of some of the rays — the illumination at P is proportional to

$$\int E_0(\lambda)\,[k_1b_1r(\lambda)+k_2b_2g(\lambda)+k_3b_3b(\lambda)]\,\mathrm{d}\lambda,$$

and thus in P we have X, Y, Z according to (5), where

$$\left.\begin{aligned} E_r(\lambda)&=b_1E_0(\lambda)\ r(\lambda)\\ E_g(\lambda)&=b_2E_0(\lambda)\ g(\lambda)\\ E_b(\lambda)&=b_3E_0(\lambda)\ b(\lambda)\end{aligned}\right\} \quad .\ .\ .\ . \quad (7)$$

Hence k_1, k_2 and k_3 in P are proportional to $K_1\,K_2\,K_3$ and thus are identical with the quantities k_1, k_2, and k_3 as defined by (6).

The part of the xy-plane (inside the triangle rgb, see *fig. 6*) is therefore truly represented on the screen, be it projectively transformed, with r, g and b corresponding to the light transmitted by the filters. The colour at P still depends upon the quantities b_1, b_2, b_3. By varying the gap widths the colour plane can thus be made to transform within itself while retaining the colours of the angular points. By means of this variation it is still possible to make the colour plane satisfy certain conditions, for instance that a prescribed point should have the colour white ($x = {}^1/_3$, $y = {}^1/_3$).

When one comes to carry out the experiment it will be found that this white gives the impression of grey. The colour at a certain point of the frosted glass can best be judged by holding in front of S_1 a screen with a small aperture. It then appears that part of the colour plane does indeed give a "white" impression. The widths b_1, b_2, b_3, if chosen

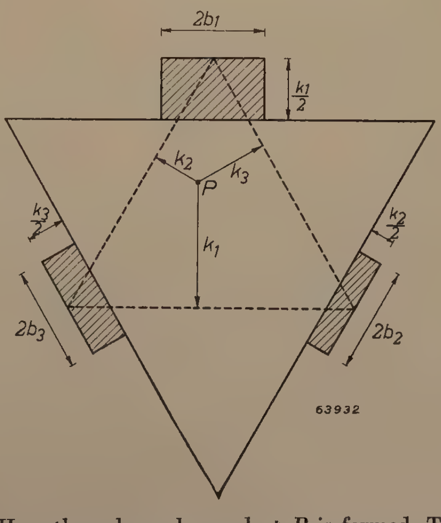

Fig. 5. How the colour observed at P is formed. To the eye with the pupil at P (imagining the frosted glass plate to be removed) only the hatched parts of the apertures r,g,b are visible.

in the right proportions, make no difference so long as the gaps do not overlap. It is therefore possible to employ also linear sources of light, the intensities of which can be adjusted separately. In principle monochromatic light sources can be used, so that the triangle *rgb* can be made to cover almost the whole of the colour plane and highly saturated colours are also truly represented, in contrast to the representation by means of paints or printers' inks.

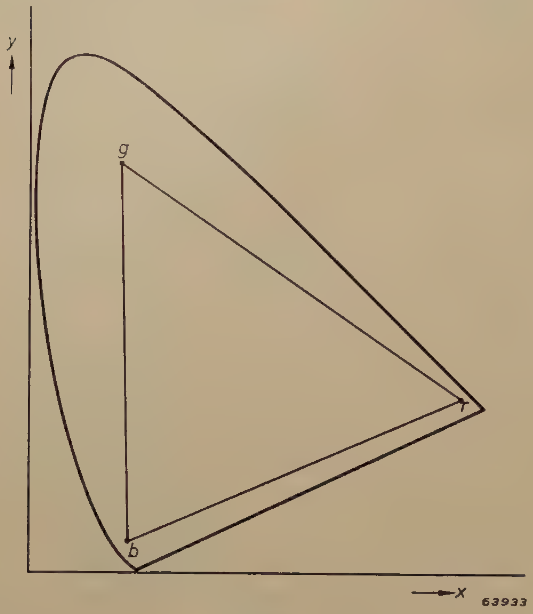

Fig. 6. The primary chromaticities E_r, E_g and E_b of formula (7) in the xy-plane.

Further, by giving the diaphragms and screens a triangular shape differing from the equilateral shape it is possible to make the colour plane congruent with a part of the xy-plane.

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Summary. In analogy with the conception of luminance (objective brightness) the conception of colour is dealt with. A brief explanation is given of the construction of the colour space in *XYZ* coordinates (I.C.I. 1931) and of the corresponding chromaticity diagram, it then being discussed in how far it is possible to give a rendering of the colour plane with the aid of oil paints. A reproduction of the result of an attempt in that direction is appended. Finally the number of chromaticities is proved to exceed 10,000 and reference is made to the difference between the conceptions of "colour stimulus" and "colour sensation".

POSITIONING OF THE SOURCES OF LIGHT WHEN PHOTOGRAPHING WITH ARTIFICIAL LIGHT

by S. GRADSTEIN.

771.44.022

For the photographer who wishes to use artificial light instead of daylight for taking photographs there are two cardinal differences between these two kinds of light: the difference in spectral distribution (colour rendering) and the difference in the geometrical situation when illuminating the object. Much has already been written about the first difference and its consequences are taken into account in the manufacture of photographic emulsions and in the construction of lamps developed for photographic purposes. The geometrical differences are usually allowed for more or less by intuition, but it may be useful to study them rather more quantitatively.

Photography as practised at the present day has two aspects, that of an expression of art and that of documentation, with sometimes the one and sometimes the other being given prominence. The aspect of documentation is clearly seen, for instance, in press photography and in medical photography, whilst also amateurs' snaps as recordings of happy memories bear more the nature of a documentation than an expression of art. As a special case of the documentary aspect is to be considered photography as applied for purposes of reproduction.

Nowadays artificial light is largely used both for artistic and for documentary photography, one of the reasons being the desire to be independent of daylight with its limitations in time and quantity. In art photography another reason is that with artificial light better means are afforded for giving expression to an object, since there is more freedom in distributing the light over the object than is possible with daylight. With daylight the whole of the sky, or that part of it which is visible, acts as the source of light. Besides this diffuse illumination there is the directed illumination from the sun, practically a point source of light at an infinite distance, the direction of which can be chosen only to a limited extent. With artificial light, on the other hand, directed light can be projected onto the object from any direction desired, even upward, and also from different directions simultaneously, so that with the play of light and shadow it is possible to give the object one's own vision of it[1]).

As regards the choice and positioning of the sources of light, in art photography there is a wealth of experience to draw upon. In a certain book on portrait photography [2]), for example, no fewer than 64 different arrangements of lamps have been thoroughly analysed. There has been no lack of attempts to distil certain recipes from the mass of experience gathered, but recipes will only be followed by those whose artistic talents are not yet fully developed; the artist photographer will always follow his own bent, guided by the artist's natural gifts of taste and intuition, accompanied by an aversion to all that is conventional. Thus the use of artificial light becomes what might be called a "lighting art".

The case where photography bears a documentary character is a more simple matter. For the illumination of the object with artificial light, as well as that with daylight, some well defined requirements can then be formulated, which may be summarized as follows: the whole of the object must be uniformly illuminated, alternated by shadows where the plasticity of the object has to be shown to best advantage, though with not too hard shadows.

When working with daylight the first two of these requirements can be met by the sun, if it is acting as the "main" or "primary light", whilst the diffuse supplementary light from the sky — or from reflecting surfaces, such as walls — may provide for the necessary softening of the shadows. When using artificial light, too, one will always have a "primary light" supplemented by "secondary lights" or by a more or less diffuse general lighting, which may be obtained from the reflection of the surroundings. But with artificial light we run the risk of failing

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[1]) Also the nature of the shadows can be influenced, namely the penumbra width, since there is a choice between sources of light of different shapes and dimensions (spot-lights, normal reflectors with or without diffusers, linear lamps, light boxes, etc.), whereas the penumbra width of direct sunlight is invariably 30 minutes of arc.

[2]) W. Nurnberg, Lighting for photography, Foco Press, London-New York, 1940.

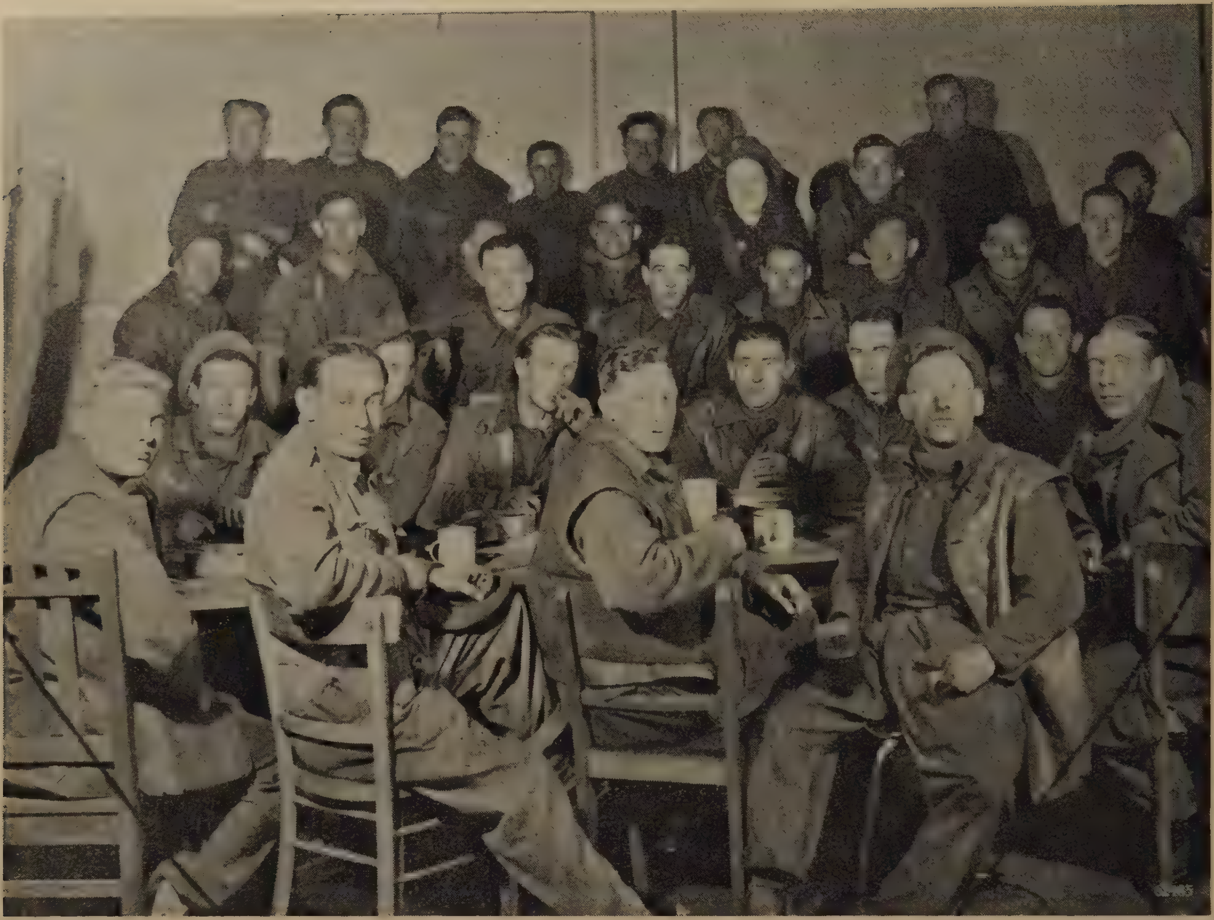

Fig. 1. Photograph showing a disturbing inequality in the illumination, falsifying the uniformity of the military uniforms. From the fall of the shadows (and the two connecting leads on the right and left!) it is to be seen that two lamps were used, placed too close to the group, presumably owing to lack of space.

to comply even with the first requirement, viz. that of uniform illumination of the whole of the object. The lamp (or combination of lamps) serving as the primary light cannot be placed at an infinite distance, like the sun, with the result that there are perceptible differences in the distances between the lamp and the various parts of the object and a certain inequality arises in the illumination of those parts.

That this risk of a discordant inequality is not imaginary can be seen from *fig. 1*, a photograph taken by a serious amateur photographer. A diffuse supplementary lighting reduces this danger, since an additive contributory illumination equal for all points reduces relatively the differences in the illumination from the main light. But also in this respect one is at a disadvantage compared with the use of daylight, because for reasons of economy (the high values of luminous flux required!) one must invariably manage with a very much smaller degree of diffusion of the illumination than is to be obtained with daylight.

Roughly speaking, the inequality in the illumination can always be sufficiently reduced if the lamps [3]) are placed far enough away from the object. On the other hand, however, — even when the fact that sometimes the space available does not permit of any great distance is disregarded — it is desired to place the lamps close to the object so as to make the most economical use of the light or to have the shortest possible exposure. It is therefore well worth while investigating what minimum distances are needed in order to satisfy the requirement of a sufficiently uniform illumination.

In this article we shall consider from this point of view some simple arrangements of lamps. The practical rules that will result from this investigation cannot, of course, substitute the experience that every photographer must himself acquire to be able to work successfully with artificial light, but they may well serve him as a guide for his experiments and they may particularly be of use in cases where the lamps are permanently fixed for one and the same kind of photographic work, like that of the professional photographer and that for reproduction purposes.

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[3]) Unless otherwise stated, where the word lamp or lamps is used henceforth this refers to the main light.

A single lamp directly facing the object

Distance requirements

Let us begin with the simple case where only one lamp is used and assume, first, that it is placed centrally in front of the object (of course slightly higher or lower than the camera). The lamp may be regarded as a point source of light with the same luminous intensity I in all directions. A small surface at a distance R perpendicular to the rays of light then receives the illumination

$$E = \frac{I}{R^2} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

Suppose that the object to be photographed has a certain depth d (*fig. 2*). The foremost parts, at a distance r from the lamp, receive the strongest illumination and those at the back the weakest; the ratio of the two values of illumination is $K = (r + d)^2/r^2$. Allowing a certain maximum value for the "inequality factor" K, we can immediately calculate the minimum permissible value of the quotient r/d. In *fig. 3*, r/d has been plotted as a function of K.

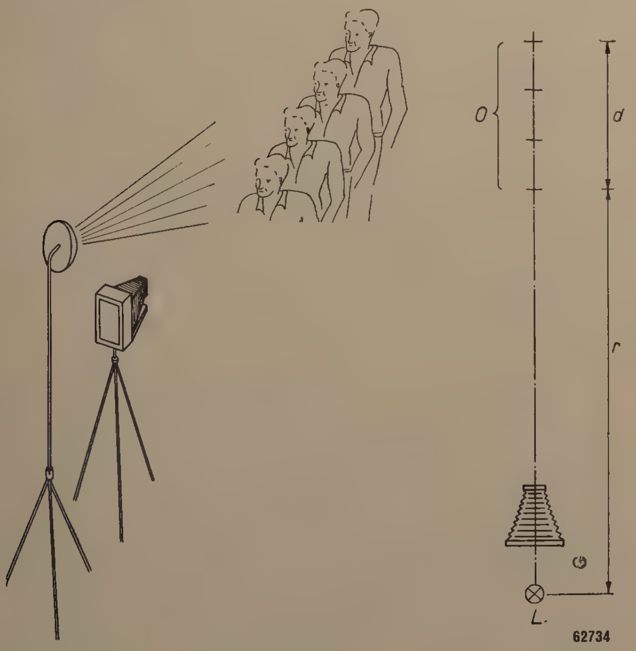

Fig. 2. A lamp L is placed at a distance r in front of the object O having a depth d.

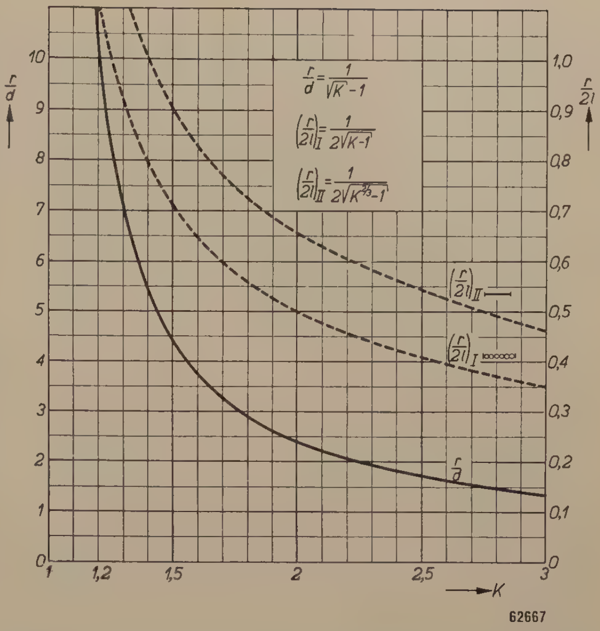

Fig. 3. Relation between the inequality factor K of the illumination and the value of r/d (fig. 2) or $r/2l$ (figs 4*a* and *b*).

It will depend upon the purpose of the photograph what value of K will in practice be considered permissible. To confine our thoughts let us take this permissible value of K as being 1.5, in which case we get:

$$r_{\min} = 4.5\, d. \quad . \; . \; . \; . \; . \; . \; . \quad (2)$$

It is reasonable to assume that in most cases an inequality factor of $K = 2$ will be judged to be rather high. On the other hand an illumination with $K = 1.2$ may be considered to be very uniform. It is only in reproduction work that values of K less than 1.2 are required.

Next to be considered is the width (or height) of the object to be photographed. Suppose that we have an object consisting of a number of persons standing side by side in a row of the length $2l$ (*fig. 4a*). The illumination at the ends of the row is a factor $K = (r^2 + l^2)/r^2$ less than that in the middle. The minimum permissible value of $r/2l$ as a function of K has likewise been plotted in fig. 3 (curve $(r/2l)_I$). For $K = 1.5$ we find:

$$r_{\min} = 0.7 \times 2l. \quad . \; . \; . \; . \; . \; . \; . \quad (3)$$

Here it is assumed, in this case too, that the surfaces in each part of the object are perpendicular to the rays of light. With a group of people as the object there are indeed surfaces in this position for each person, though they are not identical as between one person and another. We must, however, also reckon with objects where the principal surfaces to be illuminated are all parallel, an extreme example of which is an entirely flat object (fig. 4*b*) like

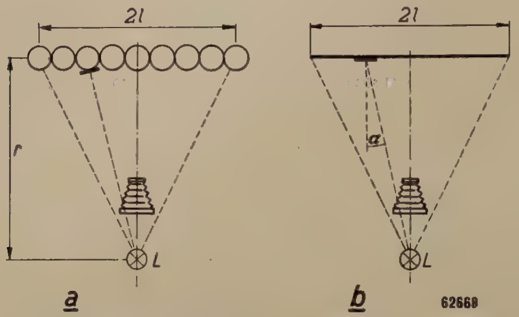

Fig. 4. A lamp L placed centrally in front of an object with a width $2l$. Where the object is a series of spheres or a row of people (a) then in each part of the object there are small surfaces perpendicular to the rays of light; with a plane object, such as in reproduction work (b), the surfaces in different parts of the object stand more or less at an angle to the rays of light.

a painting or a page of a book that has to be reproduced. In such a case the outer edges of the object are at a still greater disadvantage compared with the part in the middle, on account of the fact that they are not only farther removed from the source of the light but also stand at an angle instead of being perpendicular to the rays of light. For the illumination of a surface whose normal makes an angle α with the rays of light the formula (1) is replaced by the more general formula:

$$E = \frac{I}{R^2} \cos \alpha \,. \quad . \; . \; . \; . \; . \quad (1a)$$

For the edge of the object we have $\cos \alpha = r/\sqrt{r^2+l^2}$. The ratio for the illumination in the middle and that at the edge is now:

$$K = \left[\frac{r^2 + l^2}{r^2} \right]^{3/2} .$$

For $K = 1.5$ we then find the more stringent requirement:

$$r_{\min} = 0.9 \times 2l \quad . \; . \; . \; . \; . \; . \; . \quad (4)$$

Also for this case $r/2l$ has been drawn in fig. 3 as a function of K: curve $(r/2l)_{II}$.

The conditions contained in equations (2) and (4) have already been put forward by Van Liempt 4). Some further considerations will be devoted to this part of our subject, followed by a discussion of the more general cases, viz. those of one lamp to the side facing the object and of two symmetrically placed lamps 5).

Practical significance of the set-up considered

The method of illumination with a single lamp directly in front of the object is not commonly applied because, owing to the fall of the shadows, it does not lend any great plasticity to the photographs. This objection applies especially when photographing one single three-dimensional object, as is the case in portrait photography. Neither will this method be generally followed in the making of reproductions, on account of the disturbing reflexions.

Nevertheless there are cases where this arrangement is of importance, as in colour photography, where — with some exceptions — a plastic effect is not obtained primarily by means of shadows but rather with the aid of colour contrasts. It should be noted that in colour photography both high uniformity in the lighting and a relatively strong illumination are required, so that the foregoing is particularly applicable to this kind of photography.

Another case where the lamp is often placed directly in front of the object is that of press photography. To be able to post himself easily at the best vantage point and to take his photographs quickly in any situation arising, a press photographer usually mounts his lamp (in this case it is always a flashbulb) on the camera itself. The same principle has lately gained a remarkable popularity also in amateur photography on account of the great advantage it offers in being relieved of all the paraphernalia of stands and electric leads (and thinking about the right positioning) for taking snaps in the home. In fact cameras are now on the market with a built-in reflector for a flashbulb; an example is the Philips flash camera 6) illustrated in *fig. 5*.

Here it is to be noted that with the lamp fixed on the camera the requirement of distance derived above with respect to the width of the object is automatically satisfied. In fact the camera has only a limited field of vision. When the source of light is in the same position as the camera those parts of the object that are too far removed to the side to be properly illuminated do not appear in the photograph anyhow. Owing to lens aberrations, with a normal photographic objective only a part of the focal plane is used having a diameter

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4) J. A. M. van Liempt, Kunstlicht in de fotografie (Artificial light in photography; in Dutch), Philips Techn. Library 1942, p. 113.

5) The results of these considerations have in part already been used in a publication in "Photographische Korrespondenz" **80**, p. 101.

6) Here the lamp is mounted immediately above the lens. When working with only one lamp this position is relatively the best from the point of view of shadow formation; if the shadows cannot be softened then it is better not to have much shadow in the picture, and it is just with the lamp in this position that the eye of the camera sees almost nothing of the shadows cast by the lamp.

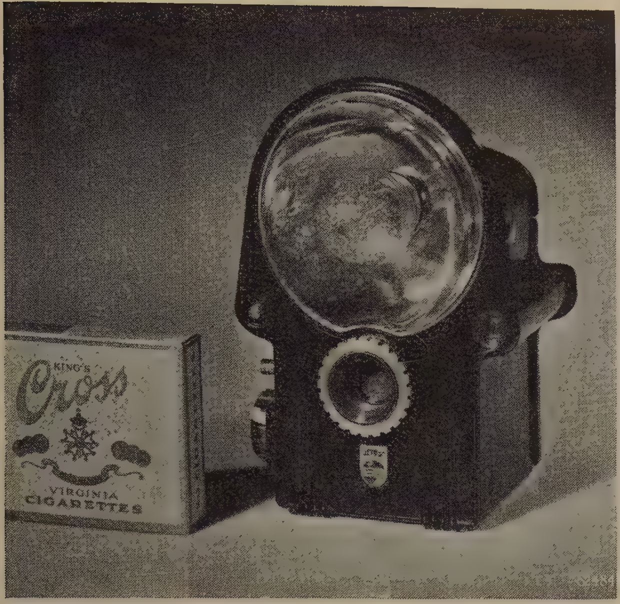

Fig. 5. Philips flash camera, type No. 5210. It contains a built-in reflector for a flashbulb. The camera is also fitted with a synchronizer, a pilot lamp for the lamp circuit, a plug socket for connecting additional flashbulb, and a compartment to take the battery for the ignition.

approximately equal to the focal length. This means, roughly, that $r = 2l$, thus $K = 1.25$ for non-planar objects [7]).

When large-angle objectives are used the foregoing no longer applies. These objectives have much larger fields of vision, corresponding, for instance, to an angle of 120°, thus $r/2l = 0.29$. If in this case the lamp were to be mounted on the camera then in the width of the object there would be an inequality factor $K = 4$ for non-planar and $K = 8$ for plane objects — apart from the effect of other causes of inequality, which will be mentioned below and which have to be taken all the more into account with such large angles.

Let us now consider the depth of the object. In this respect, too, the distance requirement derived above will automatically be satisfied, within certain limits, when the lamp is mounted on the camera, since the "field of vision" of the camera is limited also in depth, if we consider the area that the camera is able to focus. The deeper the object, the farther the camera has to be away from it in order to encompass the whole with its "focus depth". It is, however, to be noted that the ratio r/d required on that account is only greater than that according to (2) in the case of close-ups and/or when using a large relative aperture.

With some simplifying suppositions it can be deduced that the focus depth amounts to

$$d = \frac{2\,u\,m}{f^2}\,r^2\,,$$

where u represents the permissible blurring of the picture (diameter of the spot on the film in which a point of the object is pictured), f is the focal length of the objective and m = diaphragm stop (= f divided by the diameter of the objective). Taking $u \leqq f/1000$, as is mostly done for good objectives, we find:

$$\frac{r}{d} \geqq \sqrt{\frac{500 f}{m\,d}}. \quad \dots\dots\dots\dots \quad (5)$$

It is seen that m and d must not be too large, otherwise the minimum value of r/d required for focusing will not be large enough to ensure uniform lighting. Equation (5) is graphically represented in *fig. 6*, where a K-scale has also been drawn according to the relation given in fig. 3. To take a numerical example: if the lamp is mounted on a camera with $f = 11$ cm and a diaphragm stop $m = 7$ is used, then up to object depths of about 40 cm the requirement of sufficient focus depth automatically precludes any inequality in the illumination greater than $K = 1.5$. Or, to put it in other words, with these values of f and m sufficient uniformity in the illumination of the whole of the area covered by the focus depth is only ensured when the photograph is taken from a distance less than 1.80 m.

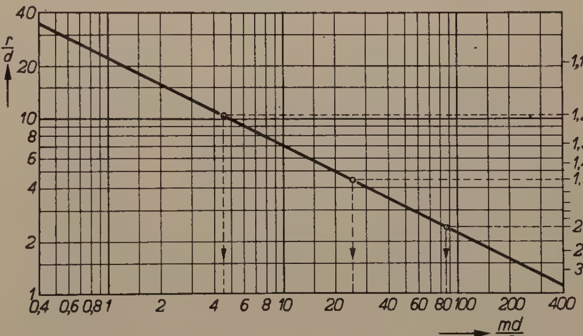

Fig. 6. To get the focus depth d the camera has to be placed at a distance r from the object. In accordance with the approximated equation (5) r/d is plotted as function of md/f (f = focal length, m = diaphragm stop). The scale on the right gives the values K appertaining to r/d according to fig. 3.

Arrangement of given objects

As a consequence of the conditions indicated in respect of uniformity, if the light from the lamp is to be used as economically as possible then a given number of objects or persons that can be placed side by side or one behind the other have to be arranged by the photographer in a certain manner. Let us assume, for the sake of simplicity, that when arranged in any order the objects cover the same area A; the considerations will be confined to the case where the objects are arranged in the form of a rectangle with width $2l$, depth d; $2\,ld = A$. If a very wide and shallow rectangle is chosen the lamp has to be placed far away on account of the condition (3); if the rectangle is made narrow and deep then the lamp has again to be at a great distance owing to the condition (2). The required distance r will have a minimum somewhere between the two. With the aid of *fig. 7a* we find the condition for sufficient uniformity of illumination ($K = 1.5$):

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[7]) Here the "width" has been measured in the diagonal of the picture.

$$l^2 + (d + r)^2 = 1.5\, r^2 .$$

Hence:

$$r = 2d + \sqrt{6d^2 + \frac{A^2}{2d^2}}\,, \quad . \;. \;. \;. \;. \;. \quad (6)$$

and taking the differential quotient of r and d as being 0 we get for the depth d of the rectangle where r is a minimum:

$$d = 0.425 \sqrt{A}\,.$$

The most favourable rectangular arrangement therefore is that where

$$2l = A/d \approx 5.7\, d\,,$$

while the lamp then has to be at a distance

$$r \approx 2.8 \sqrt{A}\,.$$

The minimum of r is not strongly pronounced, as may be seen when $r/\sqrt{A}$ according to (6) is plotted as a function of $d/\sqrt{A}$; see fig. 7*b*. The ratio of the width to the depth of the rectangle, likewise indicated along the abscissa, may vary between 3 : 1 and 10 : 1 without the required distance having to be much greater than the minimum. If, therefore, a group of, say, 24 people is to be photographed (taking for each person a circle as base) then, as far as the illumination is concerned, it matters little whether they are arranged in two rows of 12 or in three rows of 8, but it would be less satisfactory to arrange them in one row of 24 or in four rows of 6.

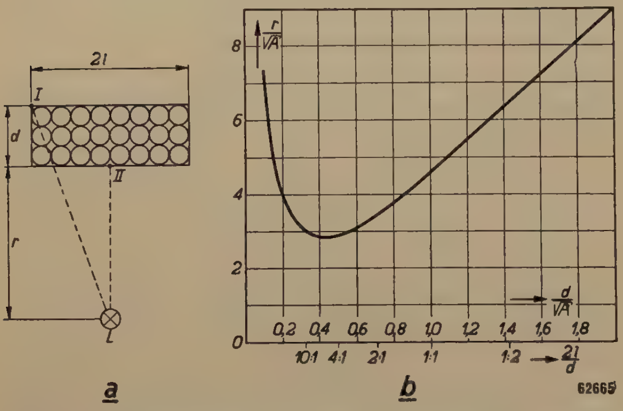

Fig. 7. *a*) A given number of objects are arranged in a rectangle. The point *I* receives the smallest and the point *II* the greatest illumination.
b) With a constant area A of the rectangle, for any shape (width $2l$, depth d) a certain minimum distance r from the source of light is required to get sufficient uniformity of the illumination. As function of the ratio $2l{:}d$ of the sides of the rectangle this distance shows a minimum at $2l \approx 5.7d$. Plotted in this diagram are the dimensionless quantities $r/\sqrt{A}$ and $d/\sqrt{A}$.

Other factors affecting the uniformity of the picture

Even though the illumination of the object in its width may be absolutely uniform, on the negative the density will still diminish from the centre towards the edges. This is due to similar causes as discussed in the foregoing in respect of the object: the distance from the "source of light" (in this case the objective) to the edges is greater than that to the centre of the photographic plate or film, and the parts near the edge stand at an angle to the rays of incident light; moreover the effective diameter of the objective is smaller for an oblique pencil of rays. These effects, taken together, cause the density to decrease as $\cos^4 \alpha$ (α = angle between the ray of light and the normal of the plate). With normal objectives the luminous intensity at the edges of the plate is consequently 25% less, and in the case of large-angle objectives even as much as 75% less, than that in the middle of the plate. Here no account has yet been taken of the effect of possible vignetting (partial shading of the diaphragm aperture by the lens mount of parts of the objective closer to the plate), nor of the fact that the light falling on the plate is not fully used owing to part of it being reflected back from the surface of the plate — two effects that become more and more pronounced the larger the angle α.

Of course the decrease in density of the negative towards the edges due to all these effects mentioned occurs just as well in photographs taken by daylight as it does in those taken by artificial light. It can only be avoided by limiting the angle α (i.e. using cameras with a reasonably large focal length), as is strongly recommended for colour photography and is the general practice in reproduction work. The results of our considerations regarding the illumination in normal cases can only be affected by this phenomenon in so far that the permissible differences in illumination between the middle and the edge of the object are further decreased, so that even greater distances from the source of light are required.

So far it has been assumed that the luminous intensity of the lamp is the same in all directions. In practice, however, this is never the case, because reflectors are always used and these more or less concentrate the light. Usually the luminous intensity within the solid angle determined by the object is not entirely constant, but shows a slight decrease — once more — towards the edges of the object; this may at times have to be taken into account.

Reflectors may also be used which give a directional distribution of the light bearing just the opposite character, the luminous flux increasing to a certain extent from the axis towards the edge of the beam ("broad radiators", such as the "Comptalux" lamp). In that case the aforementioned reduction of the illumination towards the edge of the object, and the analogous decrease in intensity of exposure of the plate, is more or less compensated and the lamp can be placed much closer to the object — closer than the camera! But then the strong reflexes and cast shadows appearing round the edges of the object may prove to be a drawback: owing to their being differently directed on opposite sides of the object these cast shadows (which are now not invisible, cf. footnote [6])) give the picture an unnatural impression.

It will presently be seen that the decrease in intensity referred to can also be compensated when using more than than one lamp as the main light.

Mention has already been made in the introduction of the equalizing effect of the diffuse supplementary light. The greater the contribution from this lighting, the more it is permissible to deviate from the conditions given for the positioning of the main light.

Finally, there is a very important factor that we have left out of consideration in all this. What counts ultimately is the difference in density in the positive, and this can be greatly influenced by the manner in which the negative is developed, or by the way in which prints are taken from it or enlargements made. When making an enlargement the photographer can print on the relatively too strongly exposed middle part by locally screening off the light. By this artifice he cannot, however, in general compensate inequalities of the illumination in the depth of the object, nor can he thereby save any parts of the negative that have been so under- or over-exposed, due to inequality of the lighting, that the details have been lost in the flat parts of the density curve of the negative.

A single lamp to the side facing the object

We shall now consider the case where one single lamp is set up not directly facing the object but to the side in front of it (some of the remarks in the previous section hold equally, of course, also for this set-up). Let the perpendicular distance to the object plane be r and the distance to the central plane perpendicular to the object s (*figs 8a* and *b*).

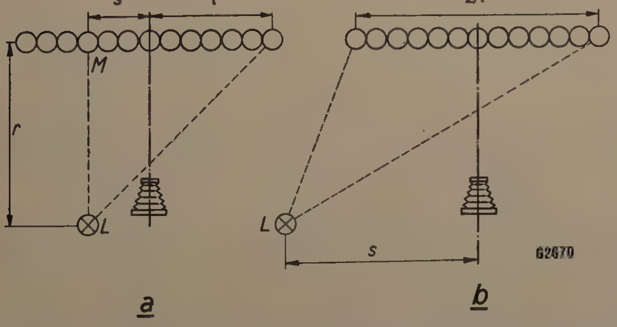

Fig. 8. A source of light L placed at a distance s from the central plane perpendicular to the object. *a*) $s < l$; *b*) $s > l$.

If $s < l$ then the part M immediately facing the lamp receives the greatest illumination, whilst the illumination is a minimum at the edge of the object at a distance $s + l$ from M. Thus the situation is analogous to that where a lamp is set up centrally in front of the object and we can again apply equations (3) and (4), only now instead of $2l$ we have to take $2(s + l)$ as the width of the object.

If the lamp is placed still farther to the side, so that $s > l$ (fig. 8*b*), then the best illuminated part lies at the nearer edge of the object and the least illuminated part at the farther edge. The ratio between the two degrees of illumination is:

$$K = \frac{r^2 + (s + l)^2}{r^2 + (s - l)^2} \quad \text{or} \quad K = \left[\frac{r^2 + (s + l)^2}{r^2 + (s - l)^2}\right]^{3/2}$$

respectively for a group and for a plane object. From this we derive the condition:

$$\frac{r}{l} \geqq \frac{1}{\sqrt{G-1}} \sqrt{\left(\frac{s}{l}+1\right)^2 - G\left(\frac{s}{l}-1\right)^2}, \quad (s > l) \qquad (7)$$

where, for a group, $G =$ the permissible maximum value K, and for a plane object $G = K^{2/3}$.

For any lateral distance s we can therefore calculate the minimum perpendicular distance r required. When we draw a ground plan of the space in which the object and the lamp are situated then all points yielding exactly the permissible value for K can be connected by a line, and this way we separate "prohibited" from "permitted" areas for the placing of the lamp. This has been constructed in *figs 9a* and *b* for the two cases of a group and a plane object. (The figure can be used for any width of object $2l$, since the conditions derived contain only the dimensionless quantities r/l and s/l.) The hatched part is free, the white prohibited. The dotted lines indicate the limits which would be obtained if the permissible difference in illumination were taken as a factor 2 or 1.2 respectively instead of 1.5.

What is most striking in these ground plans is the great economic advantage of placing the lamp centrally in front of the object ($s = 0$) as compared with a position to the side of it. When $s = 3l$, for a group, a luminous intensity about 12 times as large is needed to get the same average illumination of the object as when $s = 0$. It is true, however, that when $s = 3l$ only a much smaller angle of the light cone of the lamp is used, and we could therefore use a lamp fixture with stronger concentration of the beam (a reflector with a greater amplifying factor).

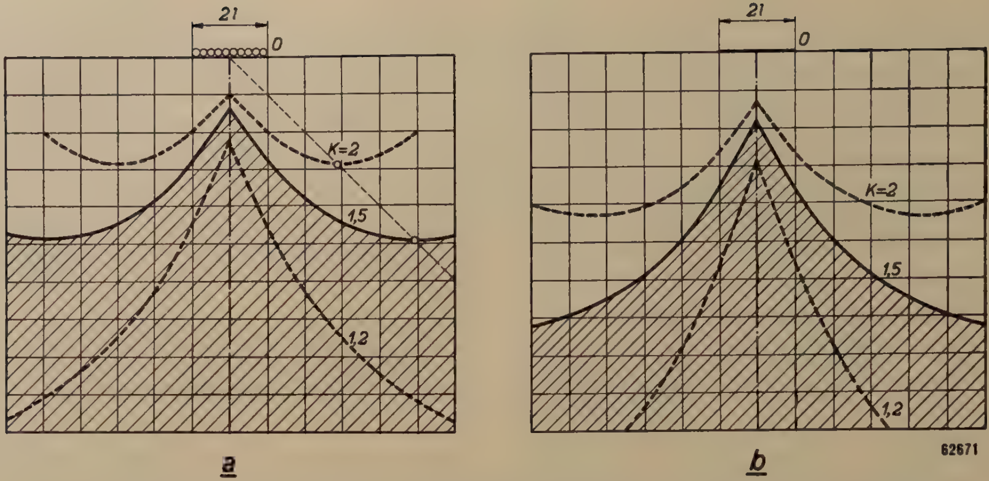

Fig. 9. Ground plans of prohibited and permitted areas (the latter hatched) for placing a source of light with respect to a given object, drawn to scale, with a permissible inequality $K = 1.5$. *a*) The object consists of a group of people placed in a row. *b*) The object is plane (reproduction).
The dotted 45° line refers to the Mohler arrangement (see in the text below).

As a special case in this connection mention may be made of the frequently applied Mohler method of illumination sketched in *fig. 10*. A powerful lamp (main light) is set up at the point $r = {}^1/_2\,R$, $s = {}^1/_2 R$, where R is the distance from camera to object, and a less powerful lamp (supplementary light) is set up close to the camera. A rough calculation shows that when the latter lamp has, say, half the strength of the primary one this supplementary light does not appreciably improve the uniformity of the illumination (of course it gives the desired softening of the shadows). With the aid of the ground plan in fig. 9*a* and the dotted 45° line, and given the distance R from camera to object, it is possible to deduce directly the permissible width of the object for this method of illumination. From the same figure (imagining the camera to be set up in the produced object line) we can also find the permissible depth, which proves to be about equal to the permissible width. We find:

$K =$	1.2	1.5	2
$\frac{d}{R} \approx \frac{2l}{R} \leq$	0.09	0.21	0.37

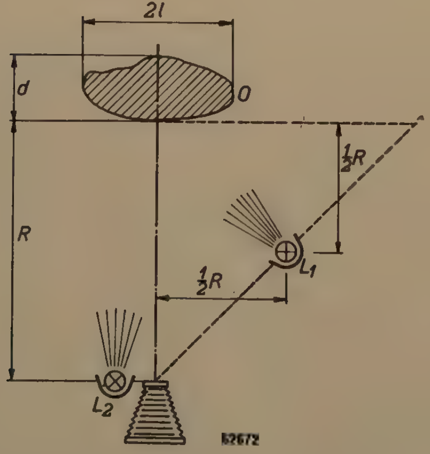

Fig. 10. The arrangement according to the Mohler method of illumination. L_1 main light, L_2 supplementary light, O object.

Two lamps set up symmetrically

The arrangement of two lamps symmetrically with respect to the central plane perpendicular to the object (*fig. 11*) is typical for reproduction work. For three-dimensional objects, with equal contributions of light from two lamps such an illumination, (not standing close together), has several drawbacks, one of which is that it produces double shadows. For plane objects, on the other hand, there are no such objections and the arrangement even has distinct advantages: the inequality in the lighting can be minimized more economically than is possible with only one lamp.

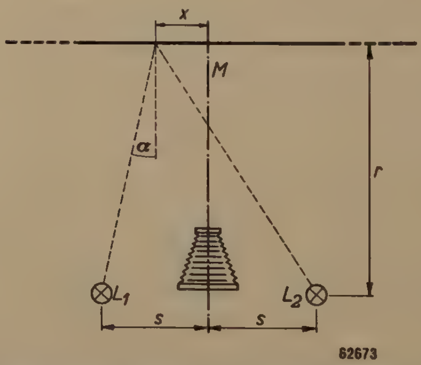

Fig. 11. Symmetrical set-up of two lamps L_1 and L_2 in front of a plane object. M is the plane perpendicular to the centre of the object.

The improvement that can be reached may be illustrated by constructing a ground plan similar to that in fig. 9*b*, but before doing so we wish to point out the advisability of including now in our considerations also linear sources of light. In normal photography linear sources of light are used only for diffuse supplementary lighting and never for the main lighting, owing to the peculiar shadow formation [8]). With the plane objects that are photographed in reproduction work however, where this objection does not hold, use is gladly made of the advantages offered by the linear source of light; in the direction parallel to the source the illumination of the object is absolutely uniform (provided the length of the source of light is greater than the distance and the dimensions of the object), and in the direction at right angles to the source the decrease in the illumination with increasing distance R from the source of light follows only the relation $1/R$ and not $1/R^2$ as in the case of a point source of light (see the article quoted in footnote [8])).

This is in fact the principle mostly applied in the apparatus employed for reproduction work, using either linear sources of light direct (*fig. 12*) or a row of point sources of light forming together approximately a continuous line (*fig. 13*). The set-up sketched in fig. 11 will therefore be considered not only with two identical point sources of light but also with two identical linear sources of light (at right angles to the plane of the drawing). For the illumination produced by a linear source of light we have to use, instead of (1a), the formula:

$$E = \frac{I_l}{R} \cos \alpha, \quad . \quad . \quad . \quad . \quad . \quad . \quad (1\text{b})$$

where I_l is defined as the luminous intensity per unit of length of the lamp.

Contrary to the cases previously dealt with, with the two-lamp arrangement it cannot be seen at once in what points of the object plane the smallest and the greatest illumination occurs. To determine this, graphical means are employed. For the illumination in a point of the object at a distance x from the central perpendicular plane of the whole set-up (fig. 11) we have for point sources of light:

$$E = \frac{I}{r^2\left[1+\left(\frac{s}{r}-\frac{x}{r}\right)^2\right]^{3/2}} + \frac{I}{r^2\left[1+\left(\frac{s}{r}+\frac{x}{r}\right)^2\right]^{3/2}} \quad (8\text{a})$$

and for linear sources:

$$E = \frac{I_l}{r\left[1+\left(\frac{s}{r}-\frac{x}{r}\right)^2\right]} + \frac{I_l}{r\left[1+\left(\frac{s}{r}+\frac{x}{r}\right)^2\right]} \quad (8\text{b})$$

We now plot $E{\cdot}r^2/I$ and $E{\cdot}r/I_l$ (the factors r^2/I and r/I_l affect only the level of the illumination and not its distribution) as functions of the place coordinate x/r in the object plane, with s/r as parameter describing the set-up of the lamps. In this way we get for different set-ups the distribution curves produced in *fig. 14*.

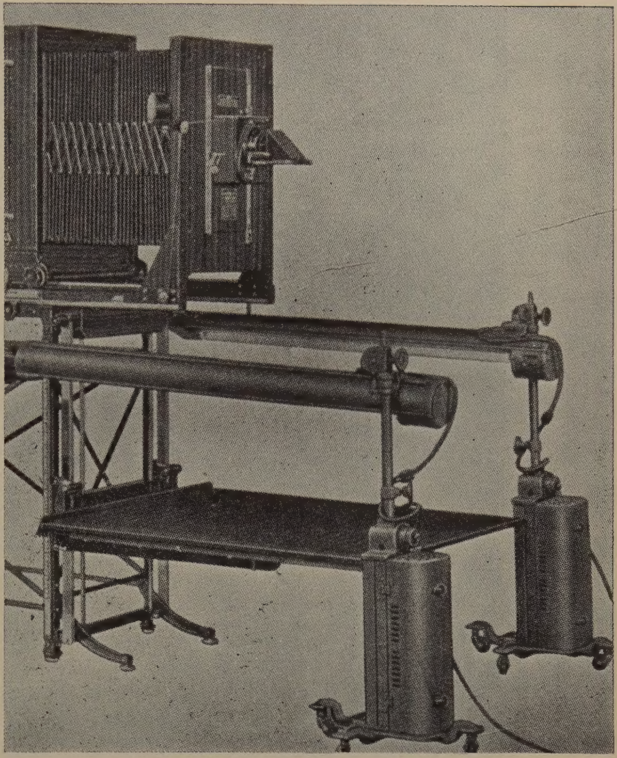

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Fig. 12. The "Photostat" reproduction apparatus (manufactured by Photostat Corporation, Inc., Rochester, U.S.A.). The plate or page of a book to be reproduced lies horizontal and is illuminated with two linear lamps (mercury lamps 1.20 m long in enamelled reflectors). In a simpler design, the "Photostat Junior", two incandescent lamps are used, thus more or less point sources of light, placed in the same way. — In a reproduction apparatus the object is photographed via a prism placed in front of the objective, thereby inverting the image. This is necessary to allow reproductions to be made direct on "positive" paper.

For each curve we ascertain up to what coordinate x/r the differences in illumination do not exceed a factor $K = 2$, or 1.5, or 1.2 (the value $K = 2$ is far too large for reproduction work but it has also been included again for the sake of completeness). In *fig. 15* the values found, $x_{\max}/r$, have been plotted as a function of s/r. From these curves we derive directly the permissible width of the object ($x_{\max}$) with a given set-up of the lamps (s and r), and inversely a relation between r and s can be derived when the object width $2l$ ($=2x_{\max}$) is given. This relation, which is the ground plan of the prohibited and the permitted areas for the symmetrically arranged point sources of light or linear lamps, is shown in *figs 16a* and *b* respectively.

It is seen that the boundary curves in the ground plan show a discontinuity on each side. This

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[8]) Cf. N. A. Halbertsma and G. P. Ittmann, Illumination by means of linear sources of light, Philips Techn. Review 4, 181-188, 1939.

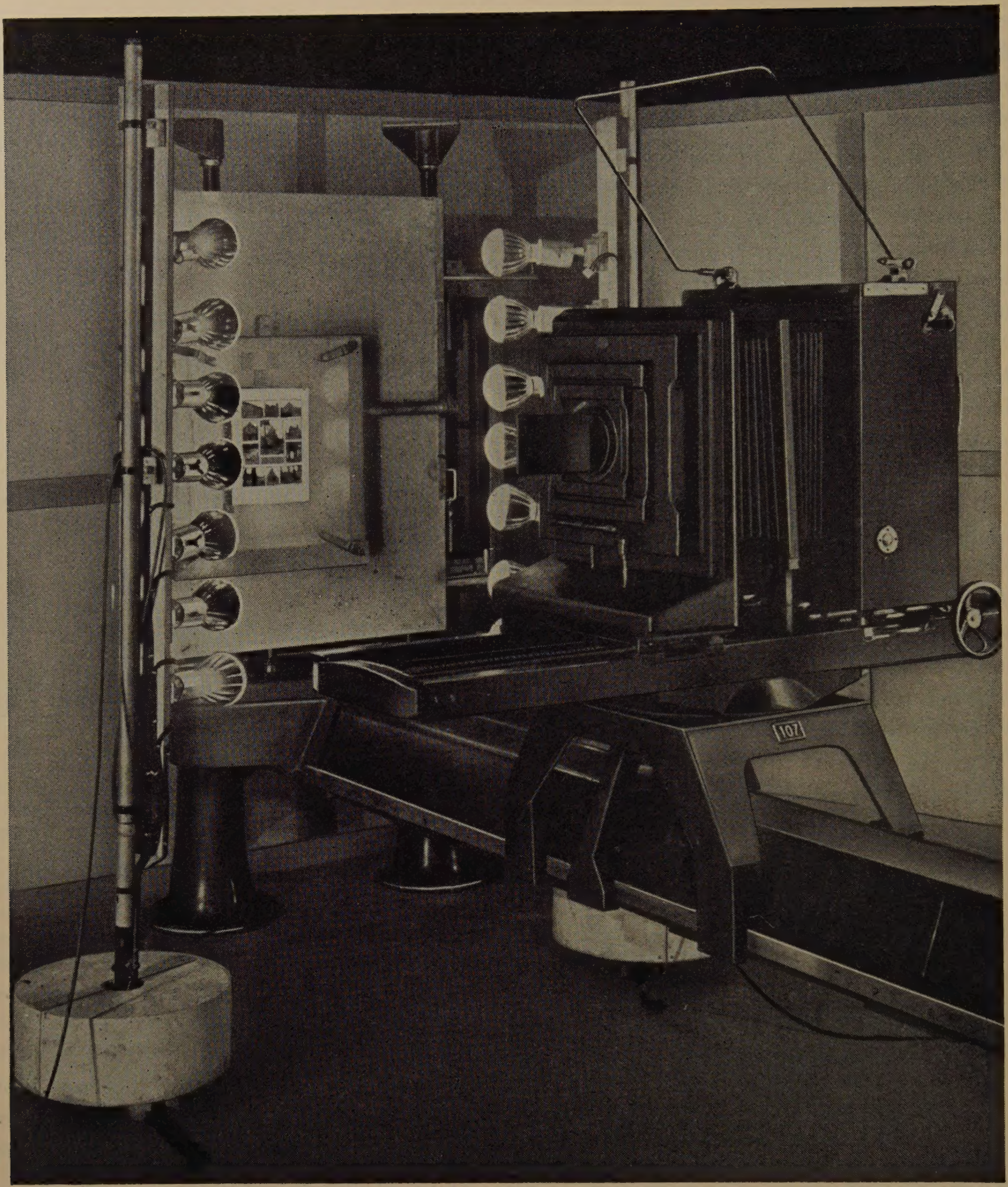

Fig. 13. Reproduction apparatus with the object illuminated by means of two vertical rows of "point" lamps (high-pressure mercury lamps in special reflectors, type HPR). (This photograph has been taken from the article by Guinau quoted in footnote [9]).)

corresponds to the jump in the curves of fig. 15 for a certain value of s/r. The significance of this becomes clear when we look closer at fig. 14. The dip in the middle of the curves is seen to become deeper the larger the value of s/r, and when a certain s/r is reached the illumination in the middle becomes exactly $1/K$ times the illumination in the two maxima. At this value of s/r the object width may extend a certain distance beyond the two maxima, but with the slightest further increase of s/r the width suddenly becomes limited to between the two maxima (and as s/r still further increases the width is confined to a decreasing part of this central area). Whereas, therefore, with a small s/r we work with the illumination distributed over the object as sketched in *fig. 17a*, with a large s/r we have to work with a distribution according to fig. 17*b*. It is seen that here we have the possibility of compensating more or less the decrease of illumination towards the edges of the negative that is inherent in the photographic camera.

The case $s = 0$ is of course identical to that of a single lamp placed centrally in front of the object. Point A in fig. 16*a* therefore answers the condition

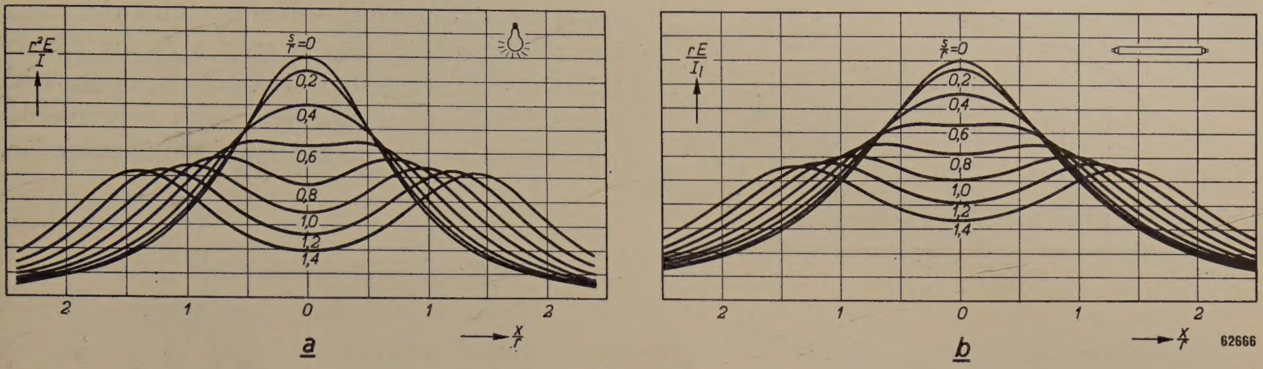

Fig. 14. Illumination (on a relative scale) as a function of the point x in the object plane with two sources of light arranged symmetrically according to fig. 11 at a mutual distance $2s$,
a) for two point sources of light; *b*) for two linear sources of light.
The distribution curve for $s/r = 0$ is the same as with one lamp placed centrally in front of the object. With increasing s/r the maximum becomes flatter, for $s/r > 0.6$ it splits up into two maxima lying at $x \approx s$, thus approximately facing each lamp.

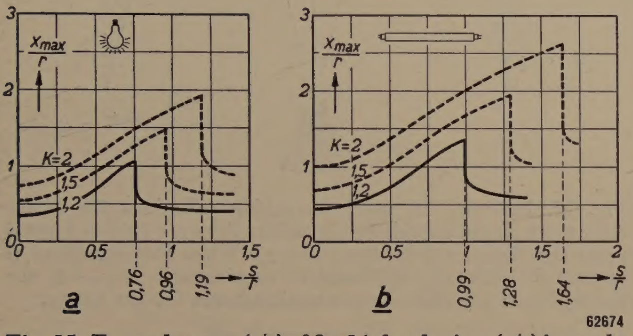

Fig. 15. For each curve (s/r) of fig. 14 the abscissa (x/r) is sought for which the illumination is a factor $K = 2$, 1.5 or 1.2 less than in the maximum (maxima) or greater than in the minimum. The values found, $x_{\max}/r$, are plotted here as functions of s/r:
a) for two point sources of light,
b) for two linear sources of light.

of equation (4). The discontinuity of the boundary curve for the same K in fig. 9*b* (boundary case of one lamp to the side facing the object) likewise falls in this point A; this curve is indicated in fig. 16*a* by a thin broken line. The advantage of using two lamps is obvious. A comparison of the ground plan in fig. 16*b* with that in fig. 16*a* demonstrates the advantage of the linear sources of light.

As regards the further choice of position of the lamps in figs 16*a* and *b*, for the most economical use to be made of the lamps — in reproduction work this is a particularly important aspect — the best would be round about the discontinuities the curves, but then the lamps would be in the field of vision of the camera [9]). Moreover, account has also to be taken of the disturbing

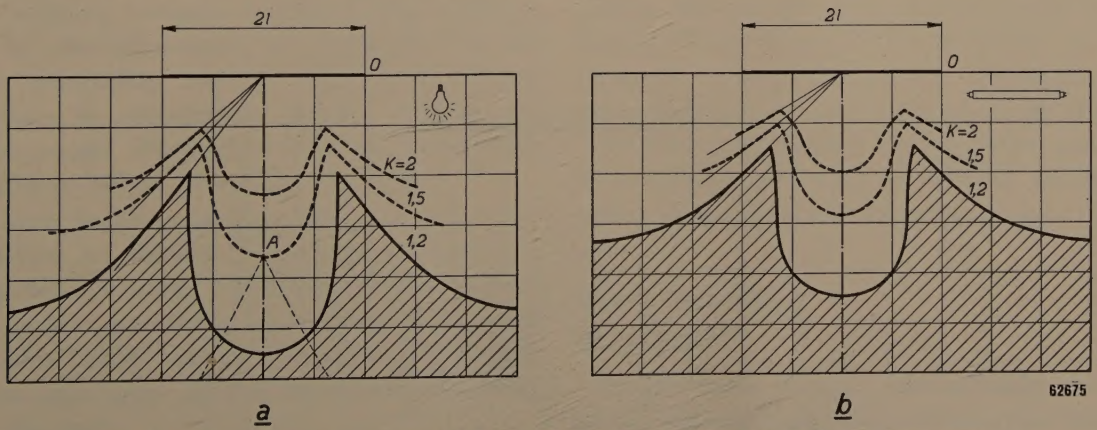

Fig. 16. Ground plan of prohibited and permitted areas (the latter hatched) for the symmetrical placing of two lamps, with a permissible inequality factor $K = 1.2$ in the illumination. The boundary lines for $K = 2$ and $K = 1.5$ are dotted.
a) For two point sources of light, *b*) for two linear lamps.

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[9]) For making "contact prints", such as are used in the production of autotype prints, where the negative or diapositive is provided with a raster (blocks, offset plates), no camera is used, so that two lamps can then quite well be placed at the discontinuities. However, for this process the system of one point source of light (a carbon arc lamp) placed centrally in front of the object is still commonly used, apparently because of difficulties in rendering the raster points owing to the Callier effect. It goes without saying that this arrangement, in the present case, where even an inequality factor of $K = 1.2$ is still too large, is very inefficient. O. A. Guinau has recommended, for this case, a series of lamps filling a square plane parallel to the plate (International Lighting Review 1949/50, No. 1, p. 26).

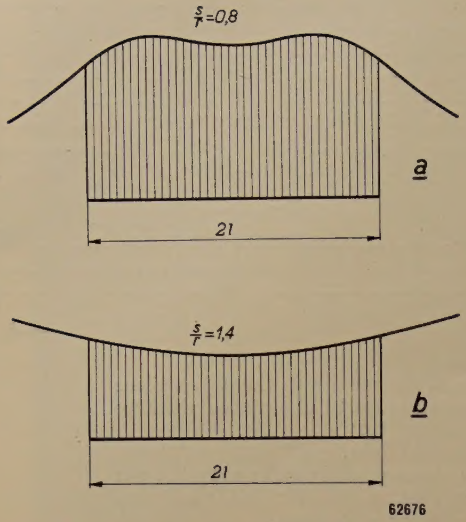

Fig. 17. Variation of the illumination over the width of the object.
a) with two lamps set up in the central area of the boundary curves in fig. 16; e.g. at $s/r = 0.8$ on the curve $K = 1.2$ in fig. 16*b*;
b) with two lamps set up on the "edge" parts of the curves (beyond the discontinuities); e.g. at $s/r = 1.4$ on the same curve as for *a*.

reflexions apt to arise when reproducing objects tending to shine. To avoid these difficulties the lamps have to set be up outside the border lines *g* drawn in *fig. 18*. By a combination with fig. 16 a permitted area is left for the position of the lamps as indicated by the hatched parts in fig. 18. The ideal position is then in the points *P*.

When two linear sources of light are used, arranged on either side of the object, the uniformity of the illumination can obviously be still further improved by adding two identical horizontal linear lamps in the places analogous to *P* underneath and over the object. The inequality factor is then reduced from $K = 1.2$ to $K = 1.1$. At the same time, it is true, an inequality is introduced in the vertical direction, which — if the linear lamps are of sufficient length — does not otherwise occur, but this inequality too is only a factor 1.1. In this way it is therefore possible to meet, with relatively simple means, very high requirements with regard to the uniformity of the illumination.

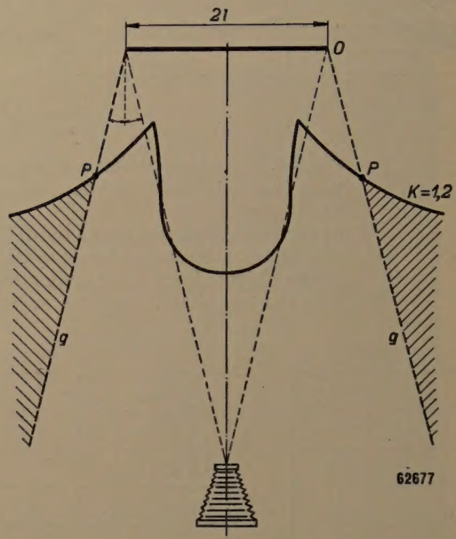

Fig. 18. In order to avoid disturbing reflexions the lamps have to be placed outside the boundary lines *g*, *g* (which depend upon the distance from the camera). When this condition is combined with the uniformity requirement $K = 1.2$ the hatched part remains as the permitted area for the lamps.

Summary. When photographing with artificial light the illumination of the object shows a certain inequality, owing to the relatively short distances between the object and the sources of light. When taking a certain permissible value, say 1.5, for the ratio of the greatest to the least illumination a number of simple rules can be formulated for the positioning of the lamps (of course this does not yet take into consideration any artistic requirements). This has been done and in this article it is explained how these rules are applied for the case where only one lamp is used, whether or not in the central plane perpendicular to the object, and for the case where two point sources of light or linear lamps are arranged symmetrically. The results are given partly in the form of ground plans on which "prohibited" and "permitted" areas for the lamps are marked off.